A COMPARISON OF PROPANE AND GASOLINE AS FUELS IN AN OTTO CYCLE ENGINE

A THESIS

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by

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Crandall

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AS FUELS IN AN OTTO CYCLE ENGINE

Approved:

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Date Approved by Chairman June 1, 1951

ACKNOWLEDGMENTS

I would like to take this opportunity to express my gratitude to Professor R. L. Allen for his advice and guidance throughout this investigation, and also my appreciation to Mr. T. D. Sangster for his cooperation in the laboratory.

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LIST OF ABBREVIATIONS AND SYMBOLS

Q	Pounds of air taken into the engine per minute.
d_w	Density of the water in the manometer corresponding to observed temperature.
d_a	Density of the air corresponding to observed temperature and barometric pressure.
h_w	The differential pressure drop across the orifice in inches of water.
C	The orifice coefficient.
D	The diameter of the orifice.
e_t	The thermal efficiency of the engine.
bhp	The brake horsepower developed by the engine.
DC	The constant of the dynamometer for power calculations.
H_f	The heating value of gasoline, 19,500 Btu/lb.
H_p	The heating value of propane, 2,522 Btu/cubic foot.
W_f	The pounds of gasoline burned per hour.
W_p	The cubic feet of propane burned per hour.
w_f	The pounds of gasoline burned per minute.
w_p	The pounds of propane burned per minute.
BP	The observed barometric pressure in inches of mercury, absolute.
DB	The observed dry bulb temperature, ^{o}Fahrenheit.
L	The load on the dynamometer in pounds.
MP	The manifold pressure in inches of mercury, absolute.
A/F	The air to fuel ratio.

LIST OF ABBREVIATIONS AND SYMBOLS (Continued)

t_p The temperature of the propane flowing through the gas meter in °Centigrade.

P_p The pressure of the propane flowing through the gas meter in inches of mercury, absolute.

T_p The absolute temperature of the gas flowing through the meter, °Rankine.

V_p The volume of gas flowing as indicated by flow meter cubic feet.

P_s The pressure of the standard atmosphere taken as 30 inches of mercury, absolute.

T_s The temperature of the standard atmosphere corresponding to a pressure of 30 inches of mercury, absolute, taken as 520° Rankine.

V_s The volume of gas flowing corrected to standard conditions.

v_{sp} The specific volume of the propane at standard condition, 8.55 lbs./cubic foot.

t The time required for 2 cubic feet to flow to the engine, seconds.

S_p The specific fuel consumption of the engine in pounds per brake horsepower-hour.

q_p The cubic feet of propane burned per minute at standard conditions.

n_v The volumetric efficiency at full throttle.

m_a Actual weight of air taken into the engine per minute.

LIST OF ABBREVIATIONS AND SYMBOLS (Continued)

m_t Theoretical weight of air to fill the piston displacement volume under atmospheric conditions.

A COMPARISON OF PROPANE AND GASOLINE
AS FUELS IN AN OTTO CYCLE ENGINE

INTRODUCTION

Purpose:

The purpose of this investigation is to compare the effects of propane and gasoline as fuels upon the performance characteristics of an Internal Combustion Engine operating on the Otto cycle. Since propane is the fuel to be compared, the subject matter will refer almost exclusively to this fuel.

Objective:

The object of this investigation is to obtain sufficient data from the operation of an Internal Combustion Engine operating on the Otto cycle burning regular gasoline and propane to plot the performance curves. These curves will be analyzed to form a conclusion to this investigation.

Review of the Literature:

Propane is a member of the paraffin series of the hydrocarbon fuels. Its chemical symbol is C_3H_8. Propane was at one time considered a nuisance by-product in the distillation of gasoline. It was burned off at the oil refineries to prevent contamination of the air around the plants. Its first commercial use was as a substitute for natural gas. A very desirable characteristic of this gas soon opened a market for it in the rural sections of the country. It can be liquified under low pressure and handled with comparative ease in a pressure cylinder, thus enabling its use from individual sources at each home. The fact that propane has an octane rating of 120, and was cheap, prompted its use in stationery industrial engines, the engines usually being near the refineries or in the oil fields owned by the refining companies. Its use has not extended considerably to the automotive field but has a potential in that direction. It is for the automotive possibilities that this investigation will be made.

Propane is obtained from two principal sources: From natural gas in the production of natural gasoline, and from refinery gases formed in the refining of petroleum. Products from the latter source contain propylene and butylene in addition to propane. Propane is a member of the same family of hydrocarbons which predominate in gasoline, but differs in that it is a gas under standard conditions of temperature and pressure and is liquified under pressure to concentrate the thermal value for economical transportation and storage. Propane is converted from a liquid to a dry gas in the fuel tank before it reaches the combustion chamber. The dry gas allows better and more thorough mixing of the fuel with the air.

Propane has most of the desirable characteristics of gasoline when used in internal combustion engines, yet possesses additional advantages. Very high anti-knock ratings which are far in excess of even the finest premium grades of aviation gasolines available today permit the use of high compression ratios. Propane burns at a slower rate than gasoline and makes for smoothness of operation because of prolonged power impulses on the power strokes and more uniform bearing pressure. All the ill effects such as thinning of the lubricating oil and washing of the oil from the cylinder walls, which greatly increase cylinder wear, are eliminated.

APPARATUS

Engine:

The engine used was a Continental Red Seal model Y-69. This engine was designed as an industrial engine for stationery use. The engine is installed in the Mechanical Engineering Laboratory and is coupled to a Taylor hydraulic dynamometer. The engine specifications are:

Bore, inches................................ 2 1/2

Stroke, inches.............................. 3 1/2

Displacement, cubic inches.................. 68.7

Compression ratio........................... 7.2:1

Number of cylinders......................... 4

Ignition System:

The ignition system of the engine was the usual equipment of the spark ignition engine. This, of course, is the point-coil arrangement with current furnished by a battery. In order to eliminate one of the possible variables, the centrifugal advance mechanism in the distributor was locked in one position. The distributor was equipped with a plate stamped with the degrees of spark advance on it. Clamped to the distributor was a pointer which would indicate the true advance of spark timing. The spark plugs were of the standard type and were the specification suggested by the engine manufacturer.

Fuel System:

The carburetion system of the engine when operating on gasoline consisted of a two gallon can resting on a Toledo scale, a fuel pump, and an up-draft carburetor. The gasoline can was connected to the fuel pump by a copper tube and was connected to the gasoline can by a very flexible rubber hose to minimize the effect of the scale platform movement upon the reading of the scale.

The carburetion system when burning propane consisted of a cylinder of gas, a pressure regulator, a gas flow meter, an atmospheric regulator and a spud-in to discharge the gas into the air stream at the venturi throat. The propane was vaporized in the tank and regulated to approximately 5 psig which was the operating pressure of the fuel regulator.

The air intake to the carburetor was connected to a large drum which served as a surge chamber to dampen the air surges through the air metering equipment. This removed the fluctuations in the manometer and allowed more accurate reading of the pressure drop across the orifice. The air used by the engine was measured by the use of an orifice. A thin plate orifice was inserted into the 2-inch pipe leading into the surge chamber. Pressure taps were made according to Vena Contracta theory[1]. The diameter of the orifice was one inch.

Instrumentation:

The engine instruments were mounted on the control panel to register the engine rpm, manifold pressure, and the oil pressure. The room temperature was registered by standard mercury filled bulb thermometers. A thermocouple was inserted into the coolant water outlet and

[1] Severns, W. H. and Degler, H. E., Steam, Air and Gas Power, John Wiley and Son, Inc., New York, 1948, p. 399

the temperature of the water leaving was maintained at 180°F. A thermocouple was also used to register the temperature of the gas flowing into the gas meter. The purpose of this temperature measurement was to correct the flow to the actual conditions. The pressure of the gas flowing was also recorded by use of an aircraft type manifold pressure gage which indicated the regulated gas pressure in inches of mercury, absolute. A gas flow meter of the type used as street meters was used to measure the gas flowing into the engine in cubic feet.

The conversion of the engine to burn propane included some modifications on the carburetor used. The carburetor used for the gasoline runs was a special up-draft type which incorporated a fuel metering valve. To modify or convert this carburetor was almost impossible and would have necessitated destruction of or rendering it useless for further use as a gasoline carburetor. An old carburetor was therefore used which was also of the up-draft type but opening to the side. This proved to be an advantage since a hole could be drilled and tapped in the bottom for the spud-in tubing to come through. The spud-in was a 3/8 inch copper tube which extended to the venturi throat where it discharged the gas to mix with the air. After installation the runs with propane were begun.

TEST PROCEDURE

Before operating the engine, the spark plugs and the points were cleaned and adjusted to the proper clearance. The lubricating oil in the engine was checked before every run. The engine was maintained in as good running condition as possible.

The runs with regular gasoline were made first and then the engine was converted to burn propane.

In order to obtain the performance characteristics over a wide range of speeds and loads, the engine runs were made at 2000, 1600 and 1200 rpm. The load on the engine was varied from full throttle to 3/4, 1/2 and 1/4 load for each engine speed. For each particular speed and load setting, runs were made with the air-fuel ratio varying from a very rich to a very lean mixture. Runs of three minute duration were made with the gasoline and the time to burn two cubic feet of gas was taken when burning propane. The purpose of these data was to plot the efficiency and brake horsepower against the air-fuel ratio. From these curves for each speed and power setting was obtained the maximum power and thermal efficiency at a corresponding air-fuel ratio. From these optimum points the performance characteristics of the engine were plotted.

DISCUSSION

The observed and corresponding calculated data for the runs made during this investigation will be grouped into the following categories. The propane runs will be designated as Group A, B and C with corresponding calculated notation. The gasoline runs will be designated as Group 1, 2 and 3 with corresponding calculated data. The maximum values of the bhp and thermal efficiency for each fuel will be designated as the optimum values for propane and gasoline respectively. The volumetric efficiency will be compared only at full throttle because it is only at this point that this curve has any significant comparable properties.

The results of this investigation are shown in Tables 13 and 14 and the curves of the optimum values are plotted in Figures 28 to 36. The curves indicate that the maximum power developed when burning propane decreased approximately 5.32% to 16.15%. The thermal efficiency decreased approximately 11% to 13.85% and the volumetric efficiency approximately 7.15% to 12.4% when propane was used.

Although propane has a higher octane rating and greater heating value than gasoline, there are several factors which contribute to the decrease in power when using this fuel. The construction of the engine was such that the exhaust manifold heated the intake manifold considerably. This is an ideal condition for gasoline where the heat of the manifold helps to vaporize the fuel. When burning propane, a fuel which has been vaporized before reaching the mixing point, a hot manifold is undesirable.

The volumetric efficiency may be cited as one reason for the decrease in power. The gasoline which has to be vaporized can, in the process of vaporization, absorb heat from the air and thereby allow a greater volume of charge to be taken into the cylinder. Propane, on the other hand, is already a vapor and the volume occupied by this vapor displaces some of the air in the manifold and a smaller charge is taken into the cylinder. As a result of this condition the gasoline would have better volumetric efficiency, as indicated by the curves.

In the process of vaporization, the gasoline absorbed its latent heat of vaporization from the air in the manifold, whereas the propane already being a vapor does not have this advantage.

Another factor which may have had some effect upon the performance of the engine is the heating value of the mixture admitted into the cylinder. For gasoline, the Btu per cubic feet of a chemically correct mixture at standard conditions of 14.7 psia and 70°F is 94.5, as compared to 90 for propane. This would indicate that the gasoline mixture contained a greater capacity to release energy in the cylinder.

The decrease in thermal efficiency may be attributed to the fact that the total horsepower developed was less but the frictional horsepower would not decrease appreciably, therefore the net brake thermal efficiency would be less. Another contributing factor may have been the slower rate of burning of propane.

CONCLUSION

As a conclusion to this investigation, it seems that for an engine which is used to burn either fuel the main advantage in burning propane would be in the relative costs of the fuel and the reduction of the problem of carburetor units.

The curves of Figure 28-31 show that there is an appreciable decrease in the power developed and in the thermal efficiency of the engine when propane is used.

One advantage that might be realized with propane is the fact that propane is a gas in the cylinder and will not wash the oil from the cylinder walls. This reduces the wear on the cylinder walls. Another advantage of its being a gas is that it will not dilute the oil in the crankcase. Also, propane burns almost completely in combustion and would thereby minimize the formation of harmful carbon deposits in the engine and lubricating oil.

If it is desirable to convert an engine to burn propane exclusively and receive the advantages of this fuel, the following things could be done to the engine. The compression ratio could be increased. The manifold could be redesigned or a cold running manifold installed. Cold spark plugs might also help in this case.

A disadvantage of the use of propane would be in the handling of a liquid under pressure. A pressure tank must be used as a fuel tank. To handle the gaseous fuel under pressure a high pressure regulator and and atmospheric regulator to meter the fuel to the engine must be used.

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APPENDIX I

FIGURES

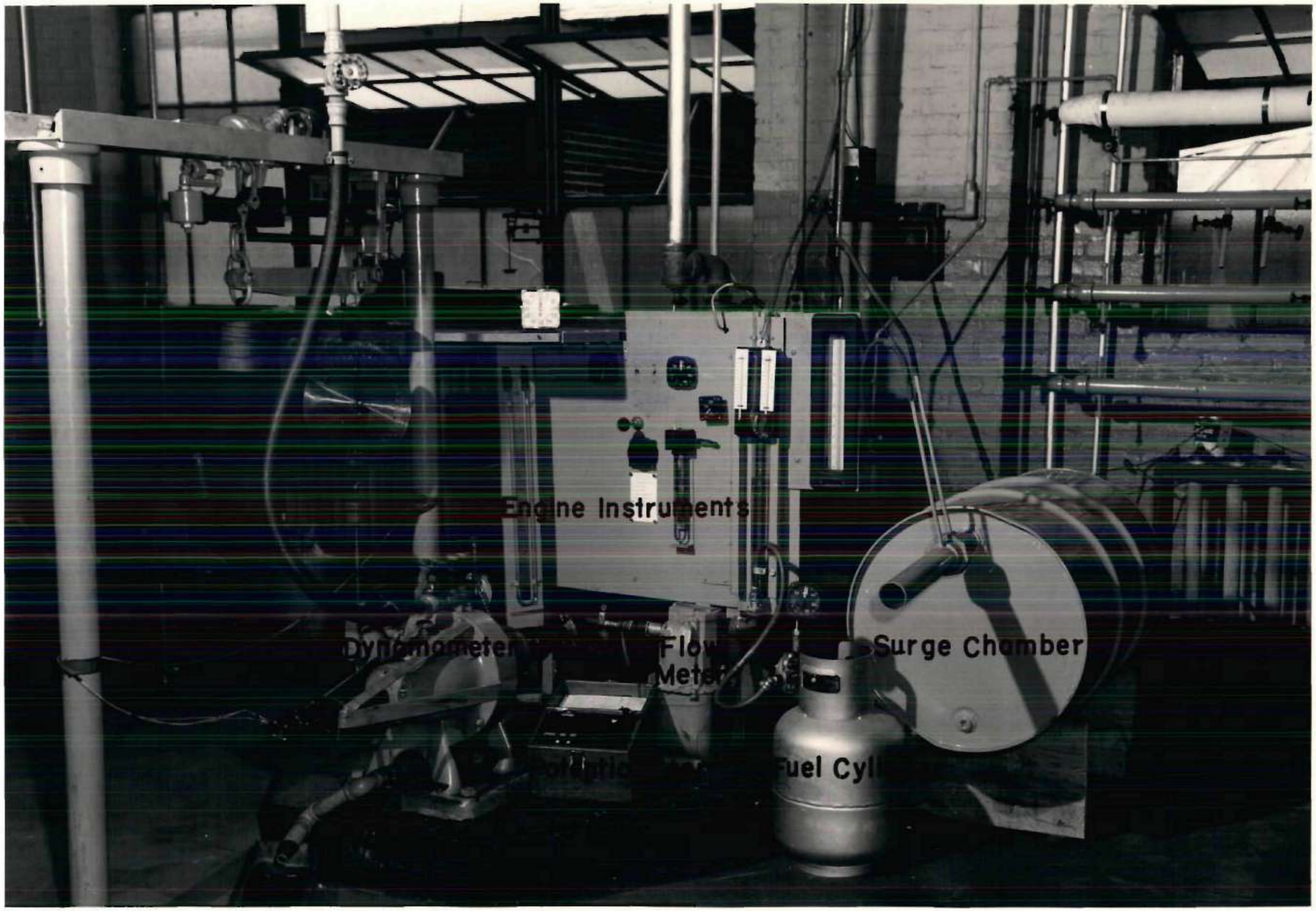


Figure 1

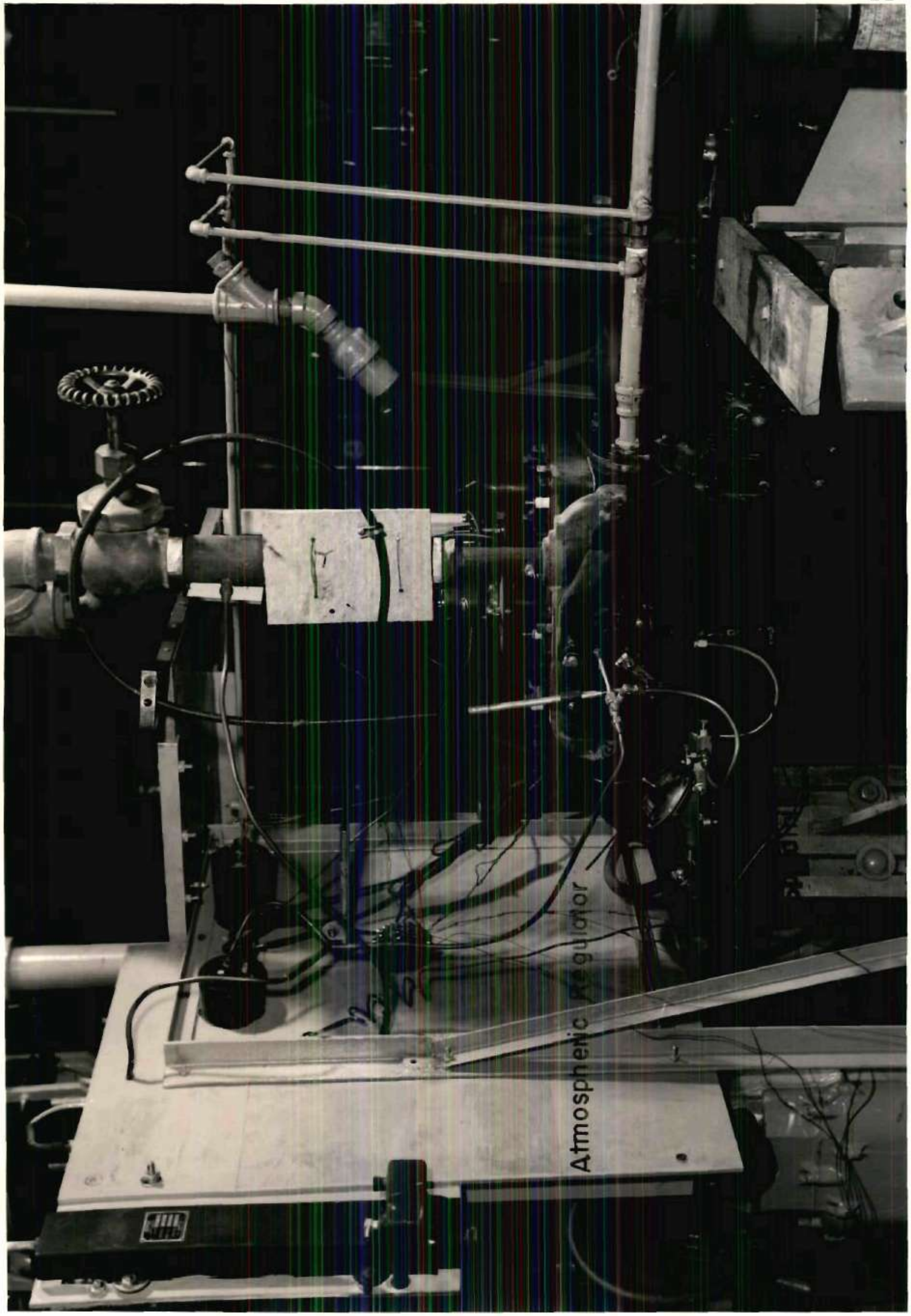
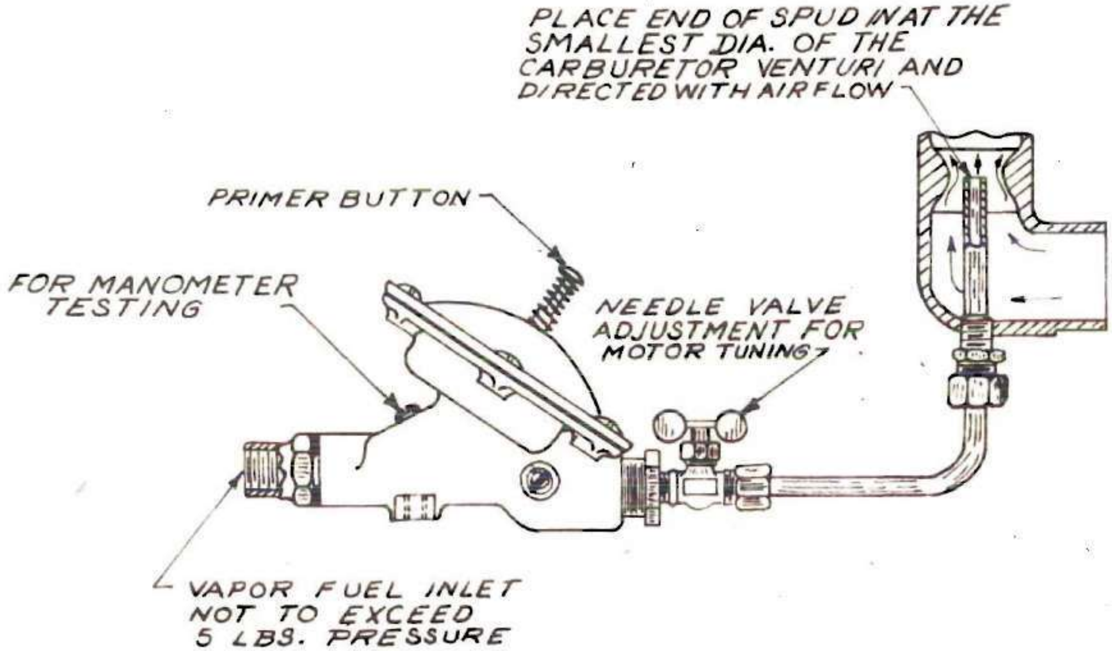


Figure 2

Figure 3



ATMOSPHERIC REGULATOR

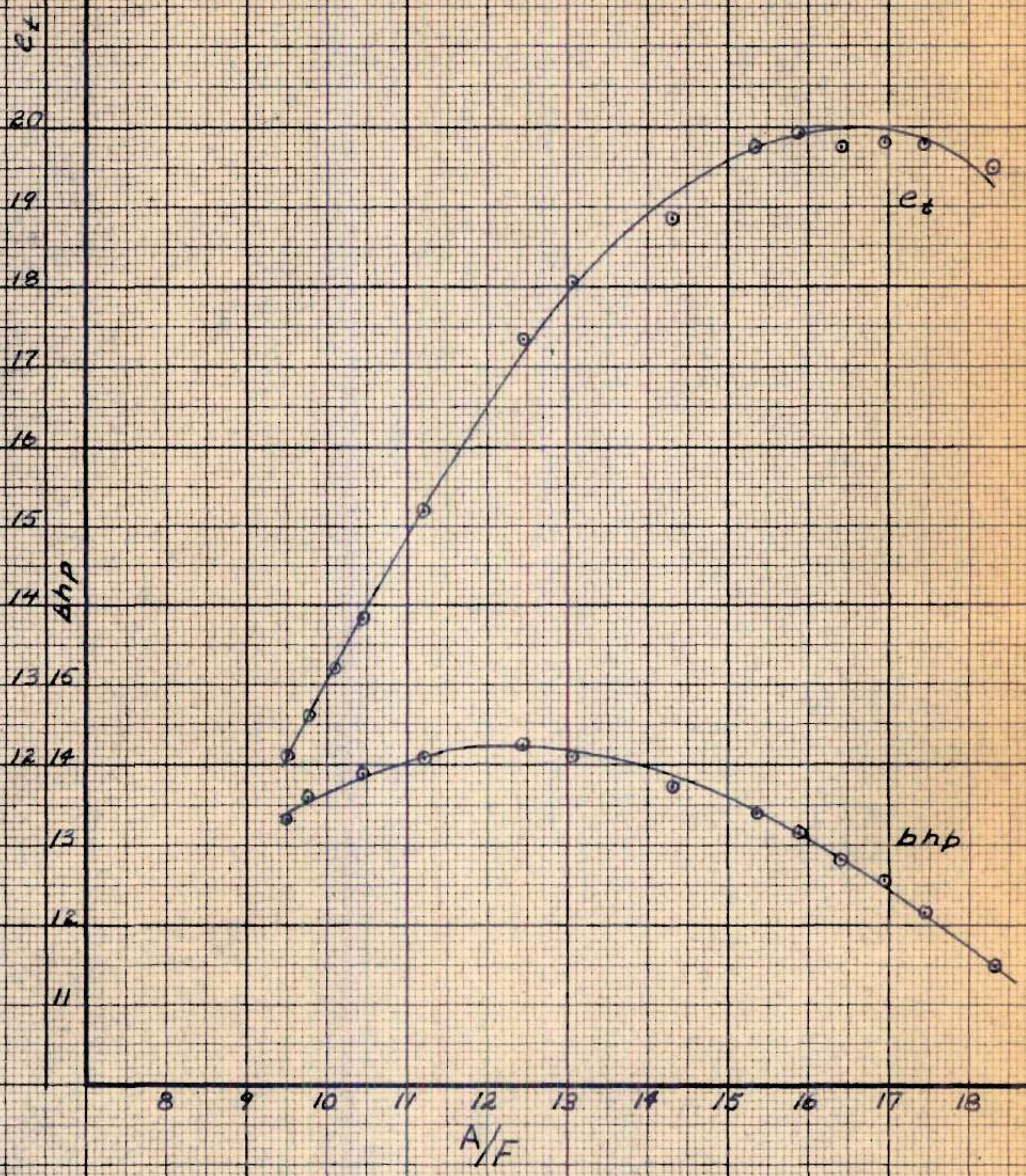


FIGURE 4
PROPANE 2000 RPM
FULL THROTTLE

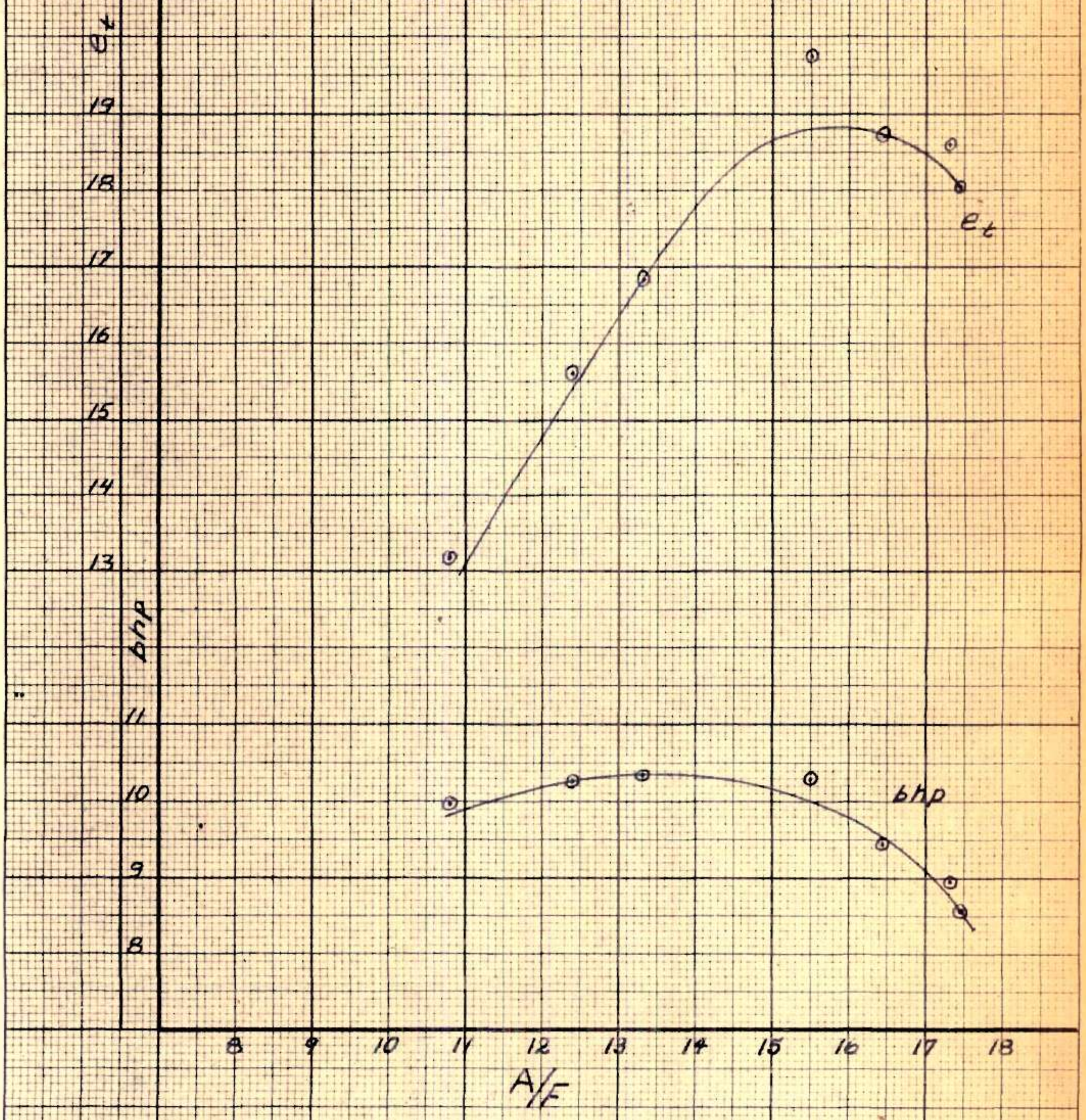


FIGURE 5
PROPANE 1600 RPM
FULL THROTTLE

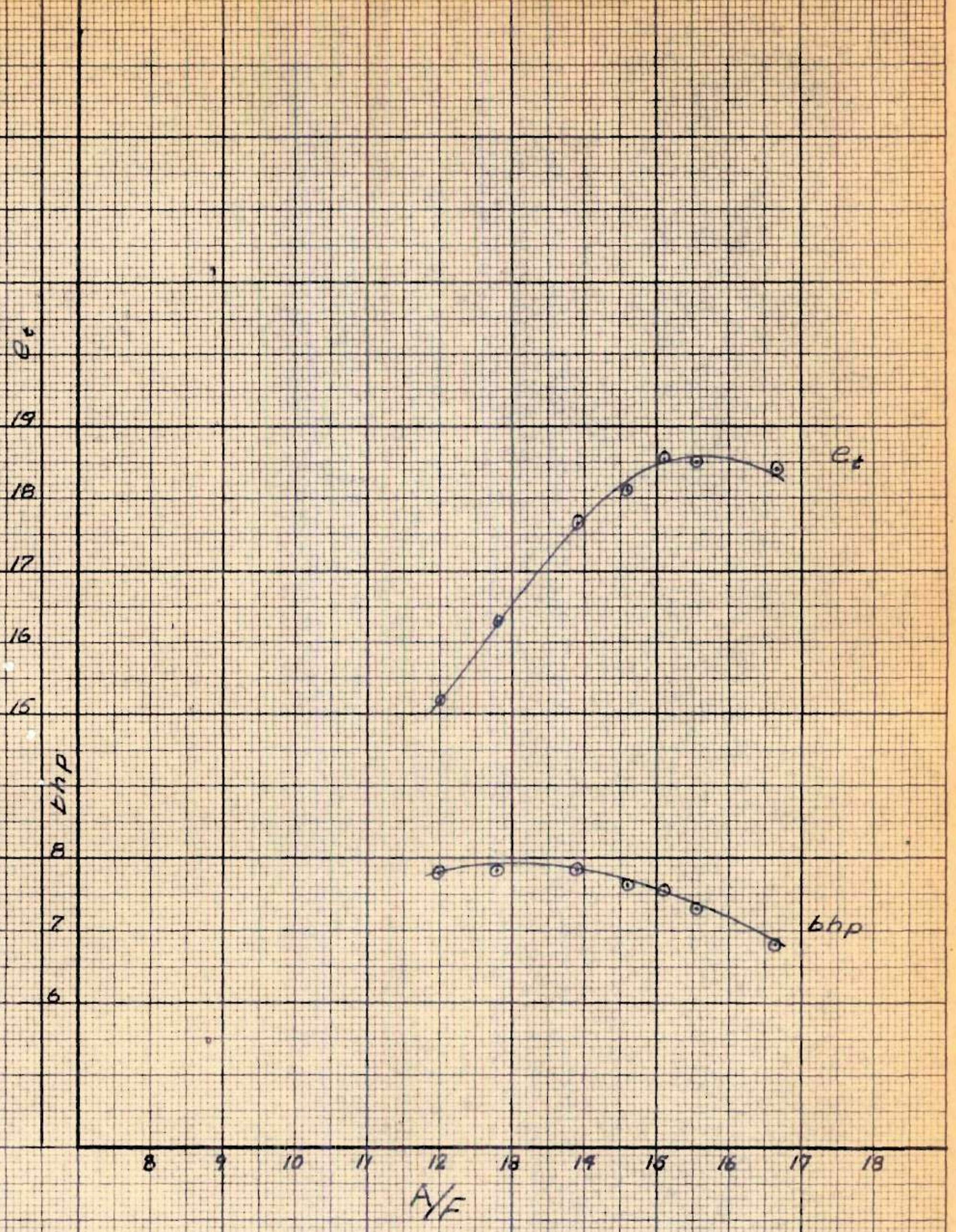


FIGURE 6
PROPANE 1200 RPM
FULL THROTTLE

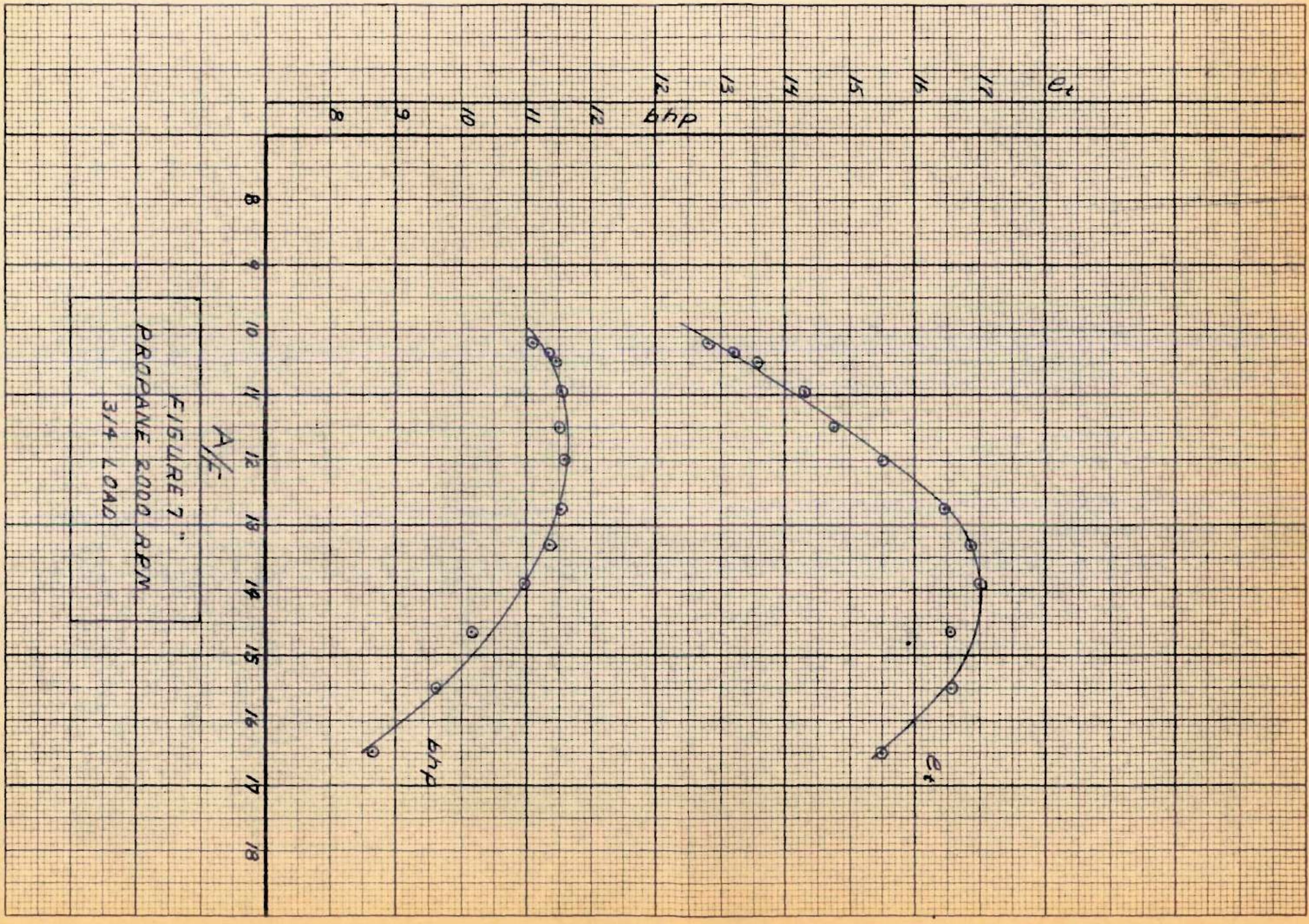


FIGURE 7
PROPANE 2000 RPM
3/4 LOAD
A/F
bhp
e_t
8 9 10 11 12 13 14 15 16 17 18
8 9 10 11 12
12 13 14 15 16 17

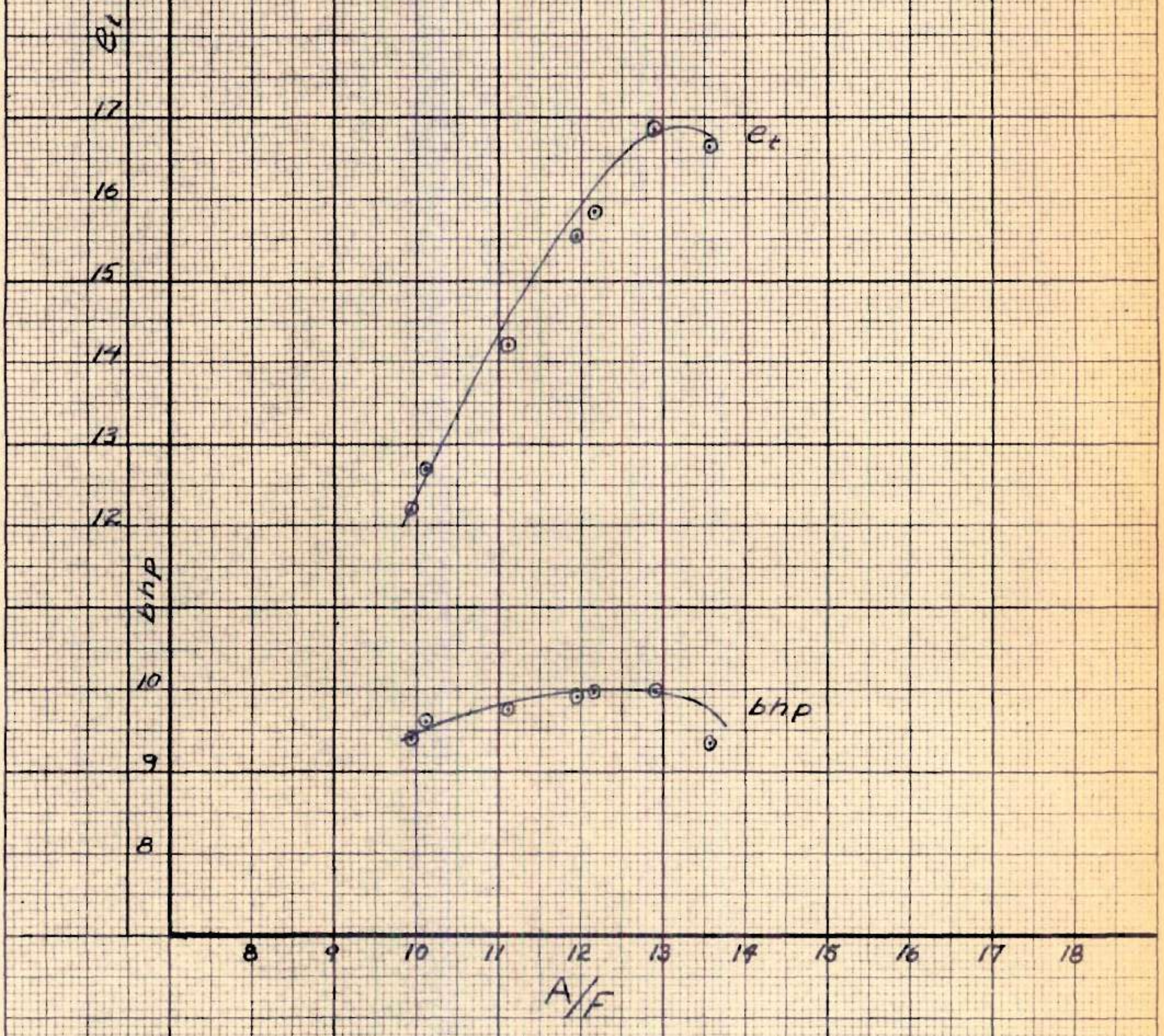


FIGURE 8
PROPANE 1600 RPM
3/4 LOAD

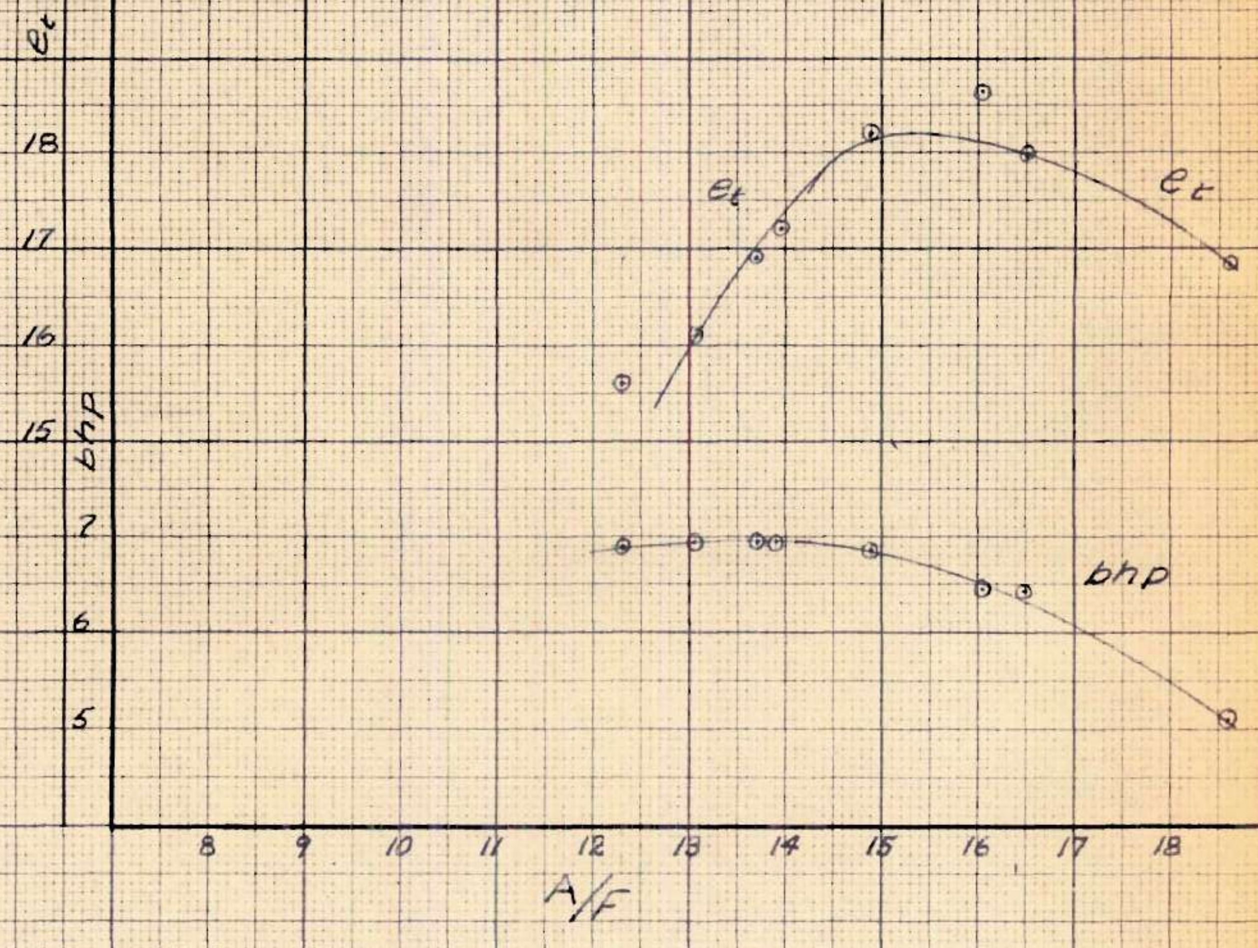


FIGURE 9
PROPANE 1200 RPM
3/4 LOAD

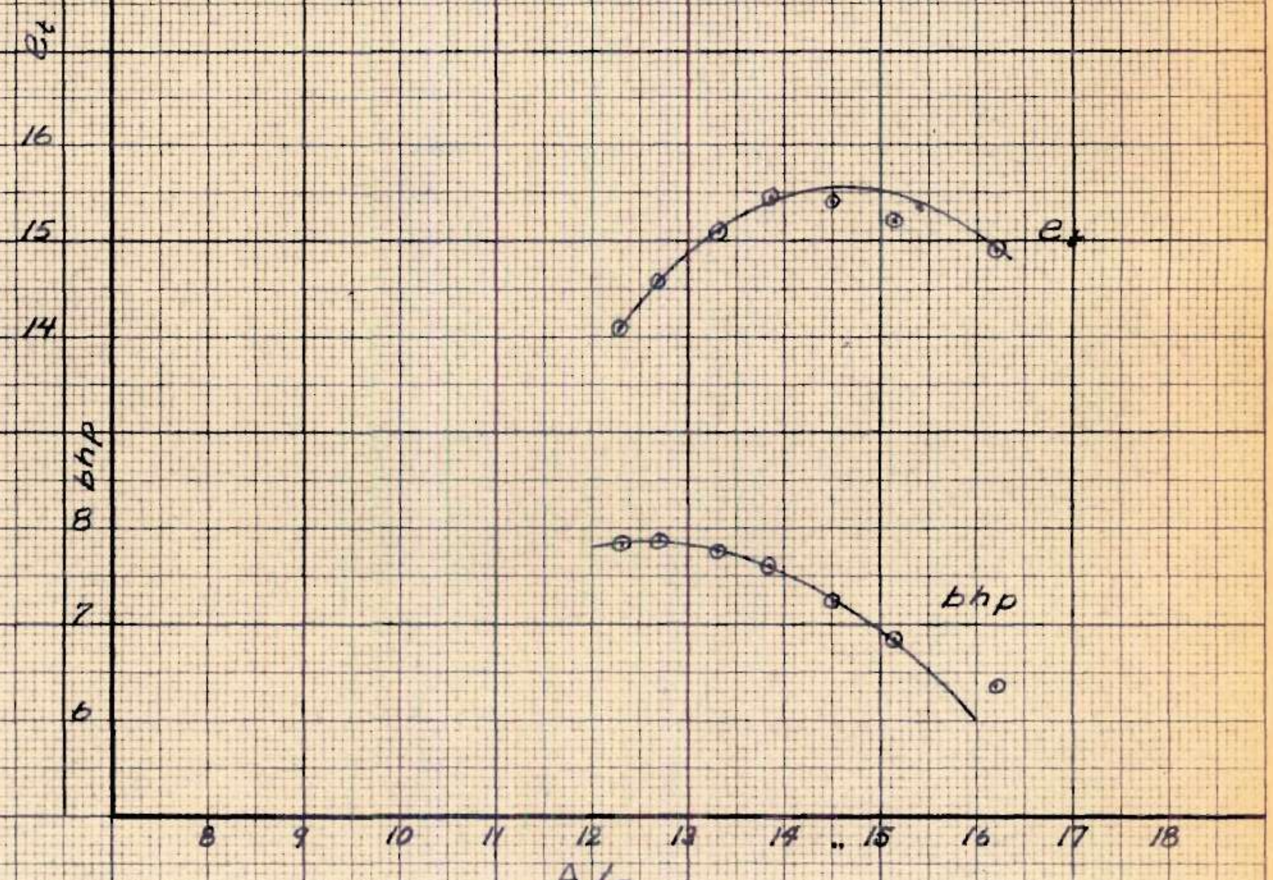


FIGURE 10
PROPANE 2000 RPM
1/2 LOAD

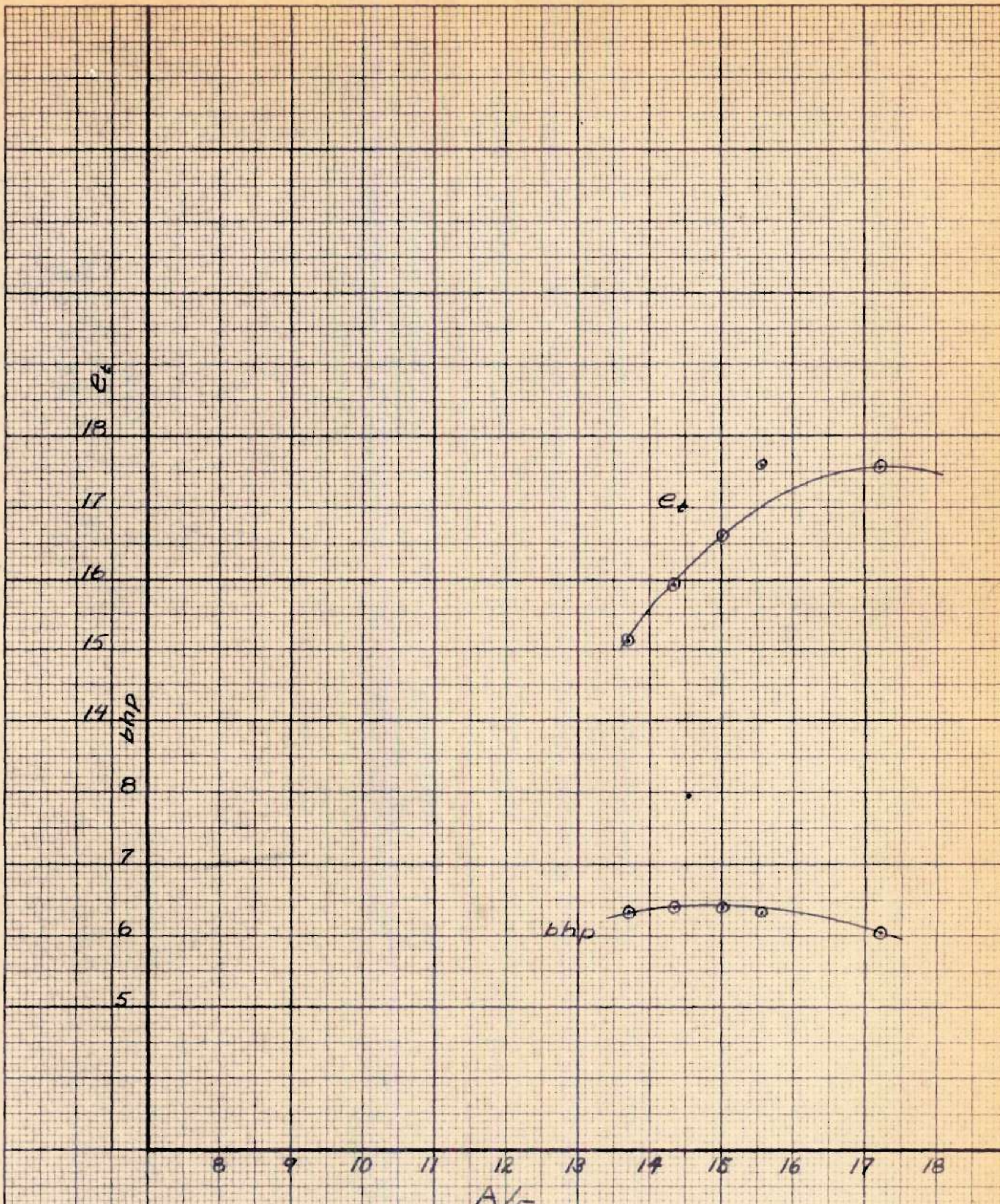


FIGURE 11
PROPANE 1600 RPM
1/2 LOAD

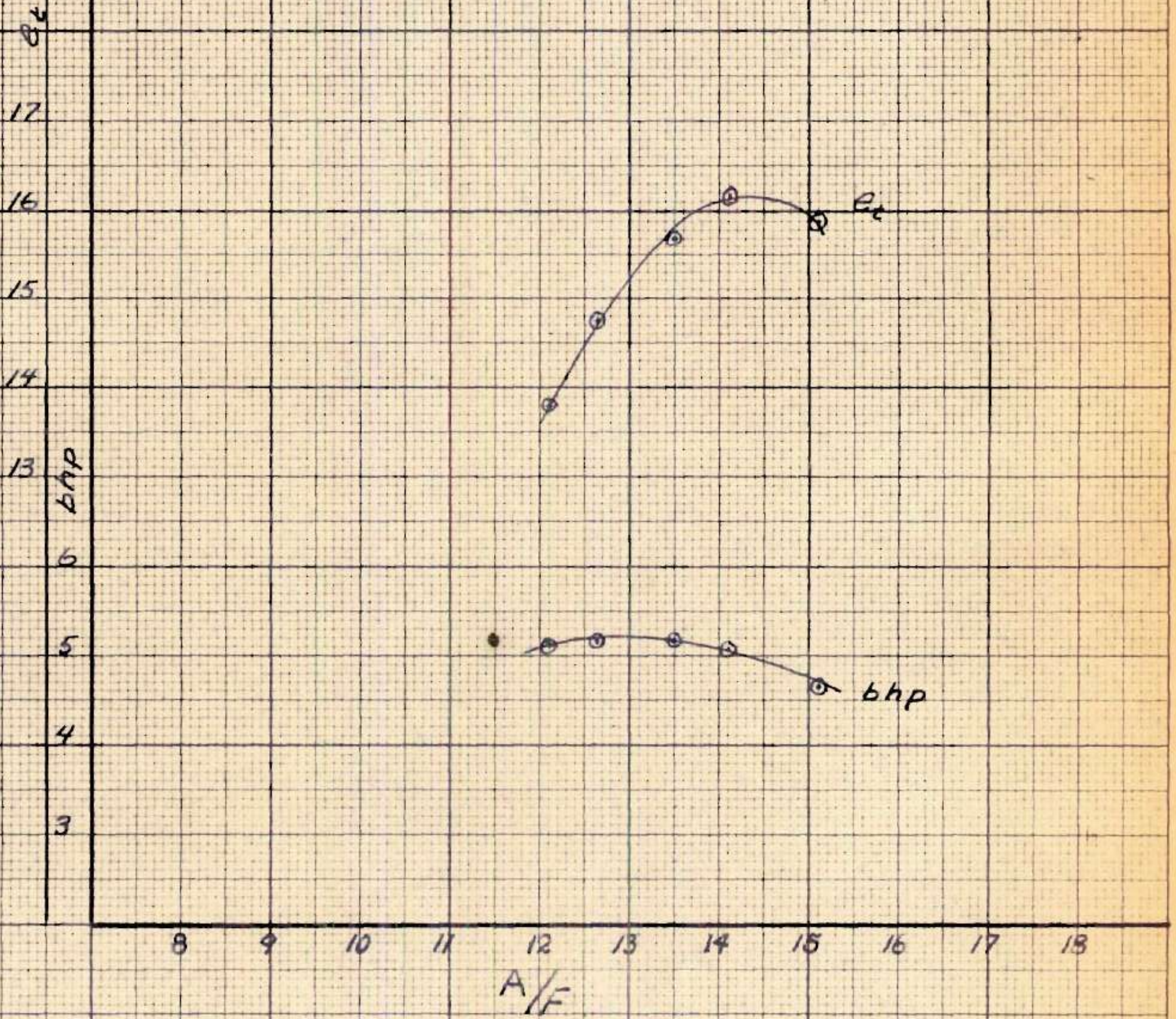


FIGURE 12
PROPANE 1200 RPM
1/2 LOAD

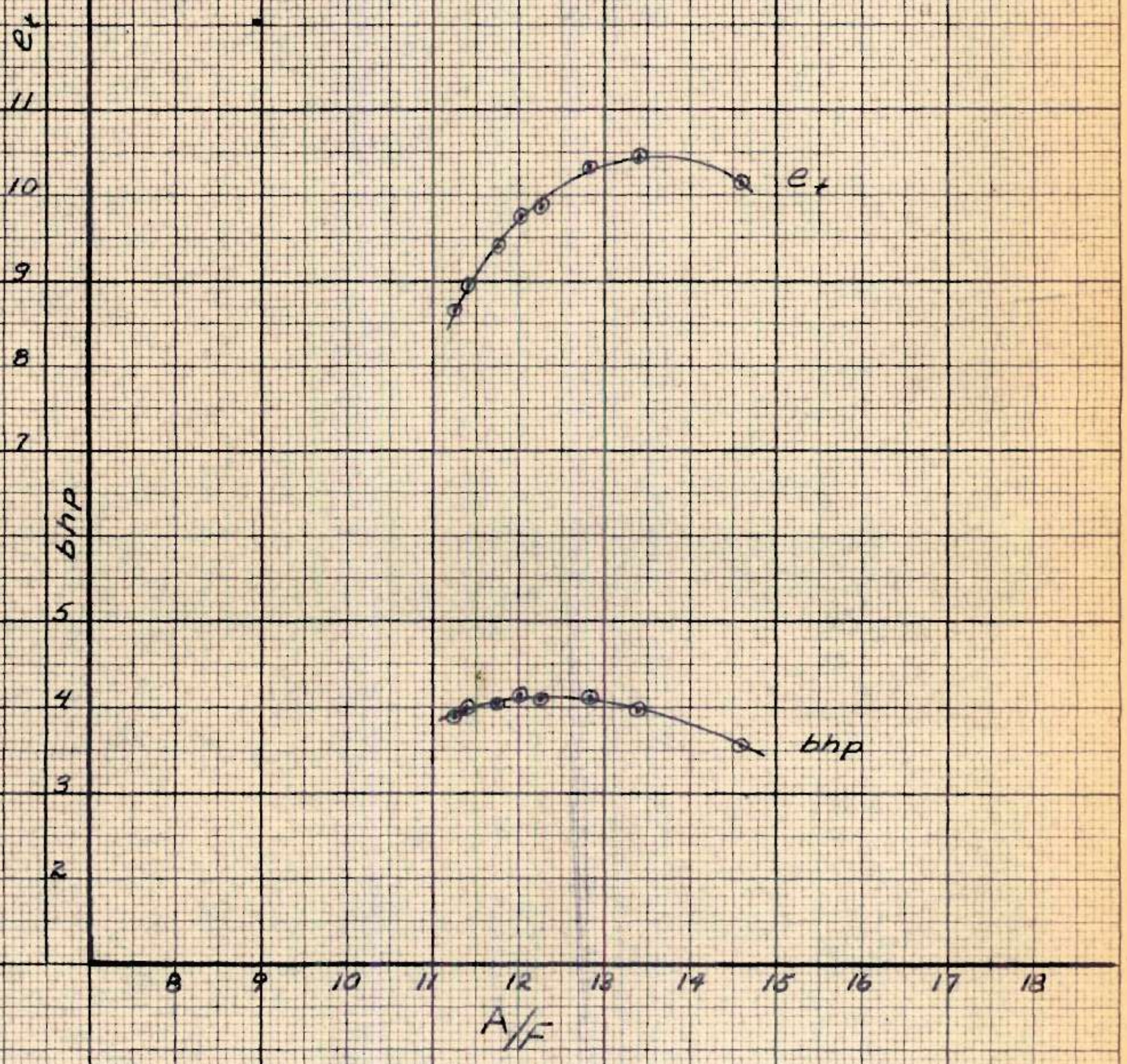


FIGURE 13
PROPANE 2,000 RPM
1/4 LOAD

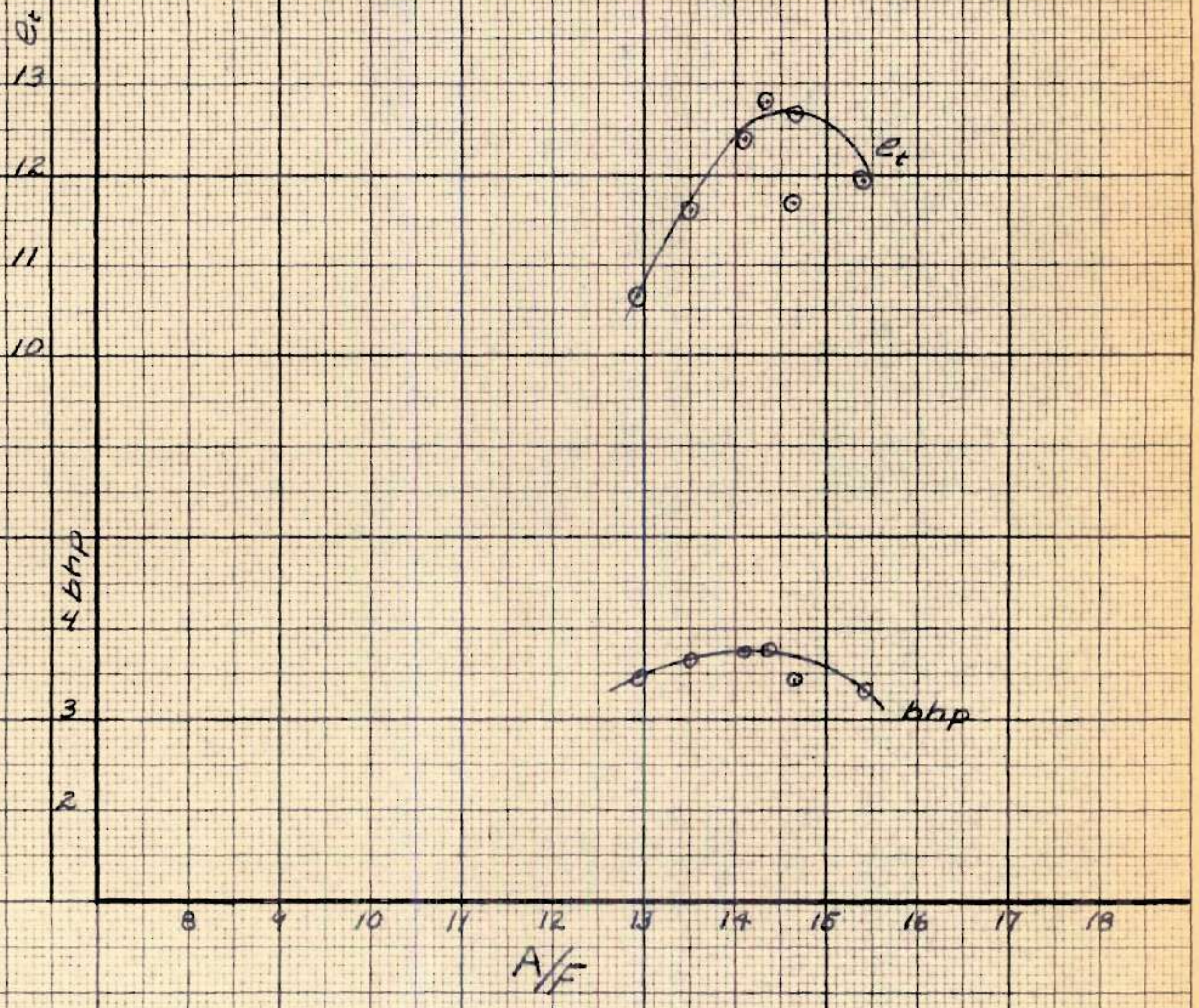


FIGURE 14
PROPANE 1600 RPM
1/4 LOAD

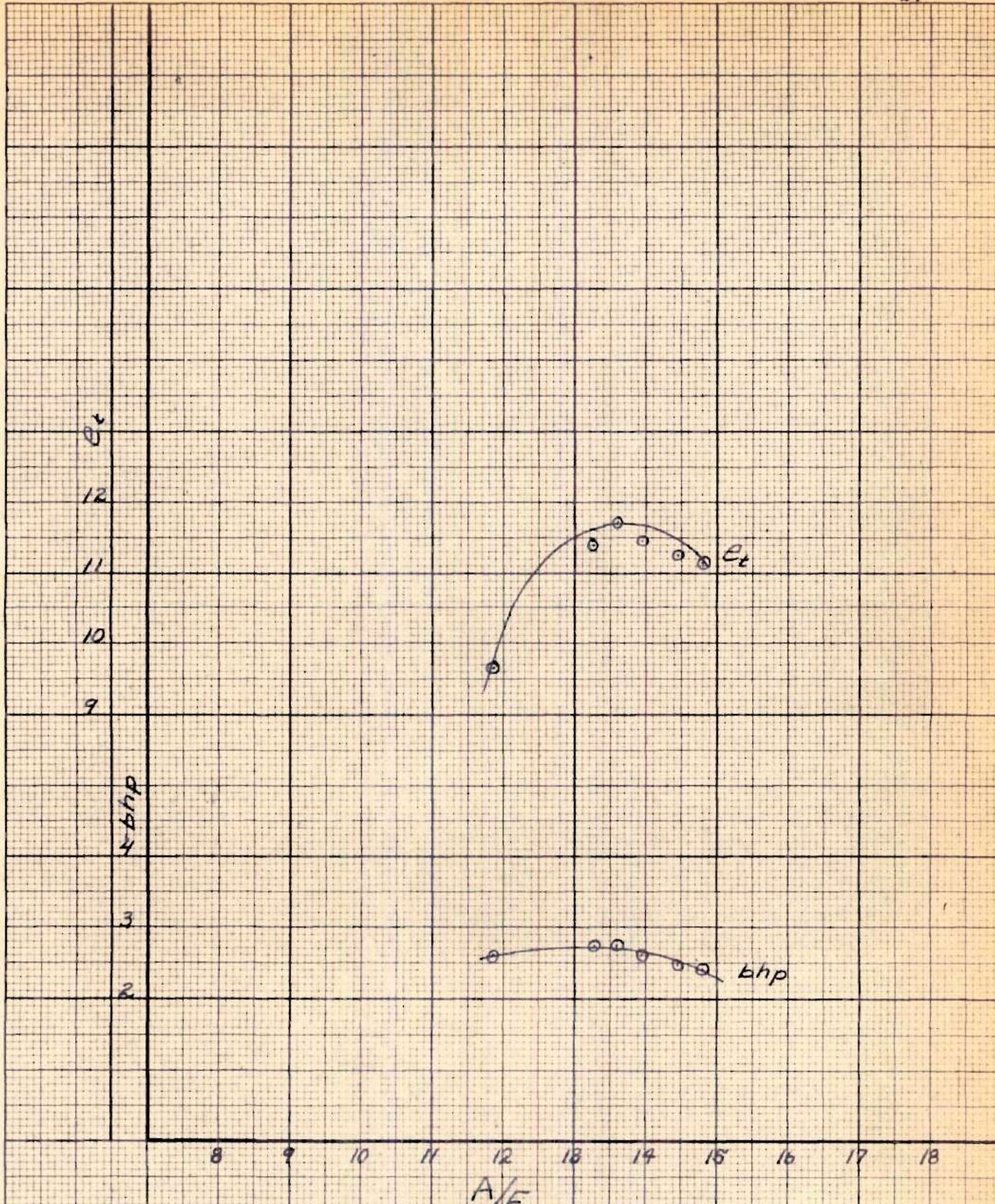


FIGURE 15
PROPANE 1200 RPM
1/4 LOAD

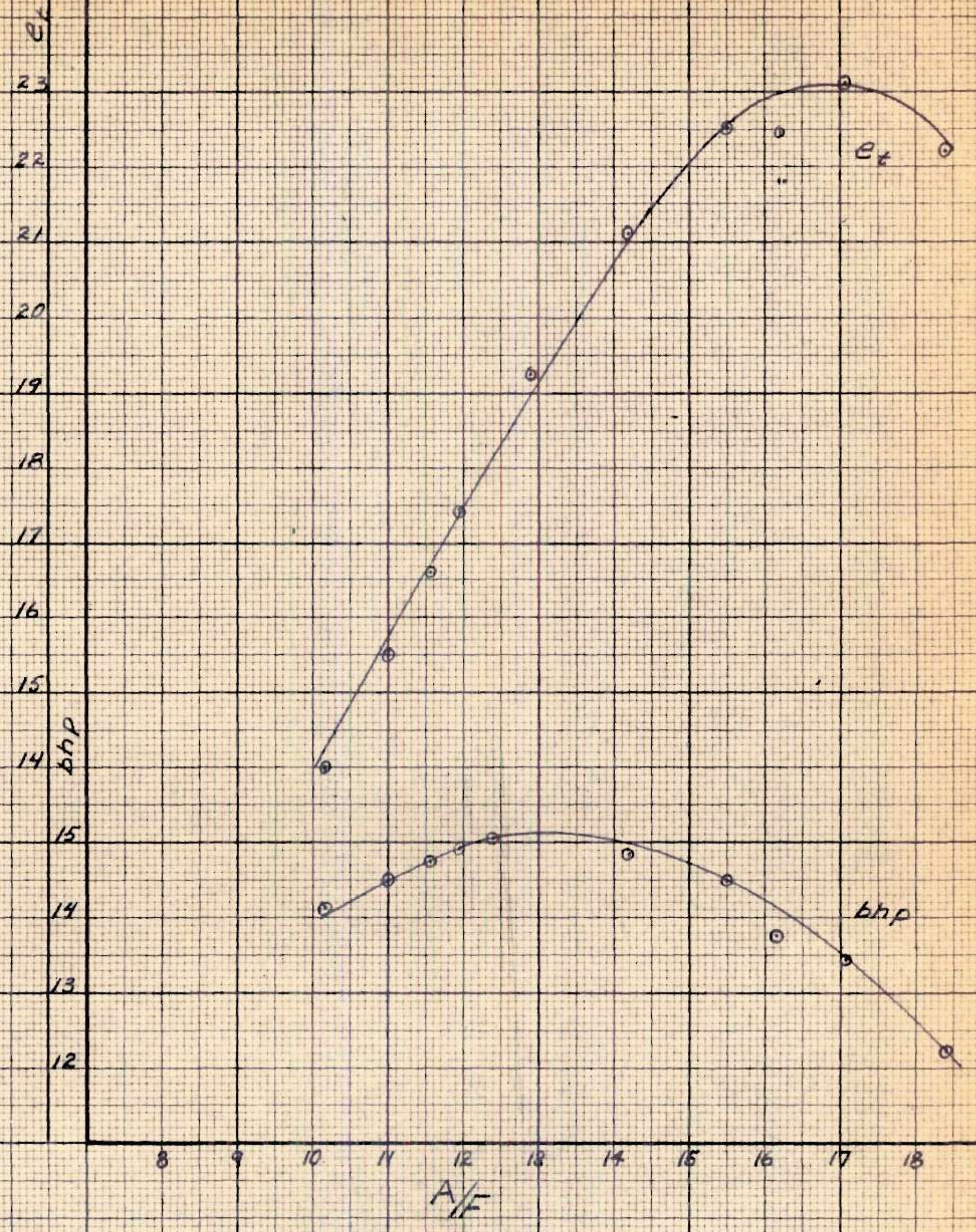


FIGURE 16
GASOLINE 2000 RPM
FULL THROTTLE

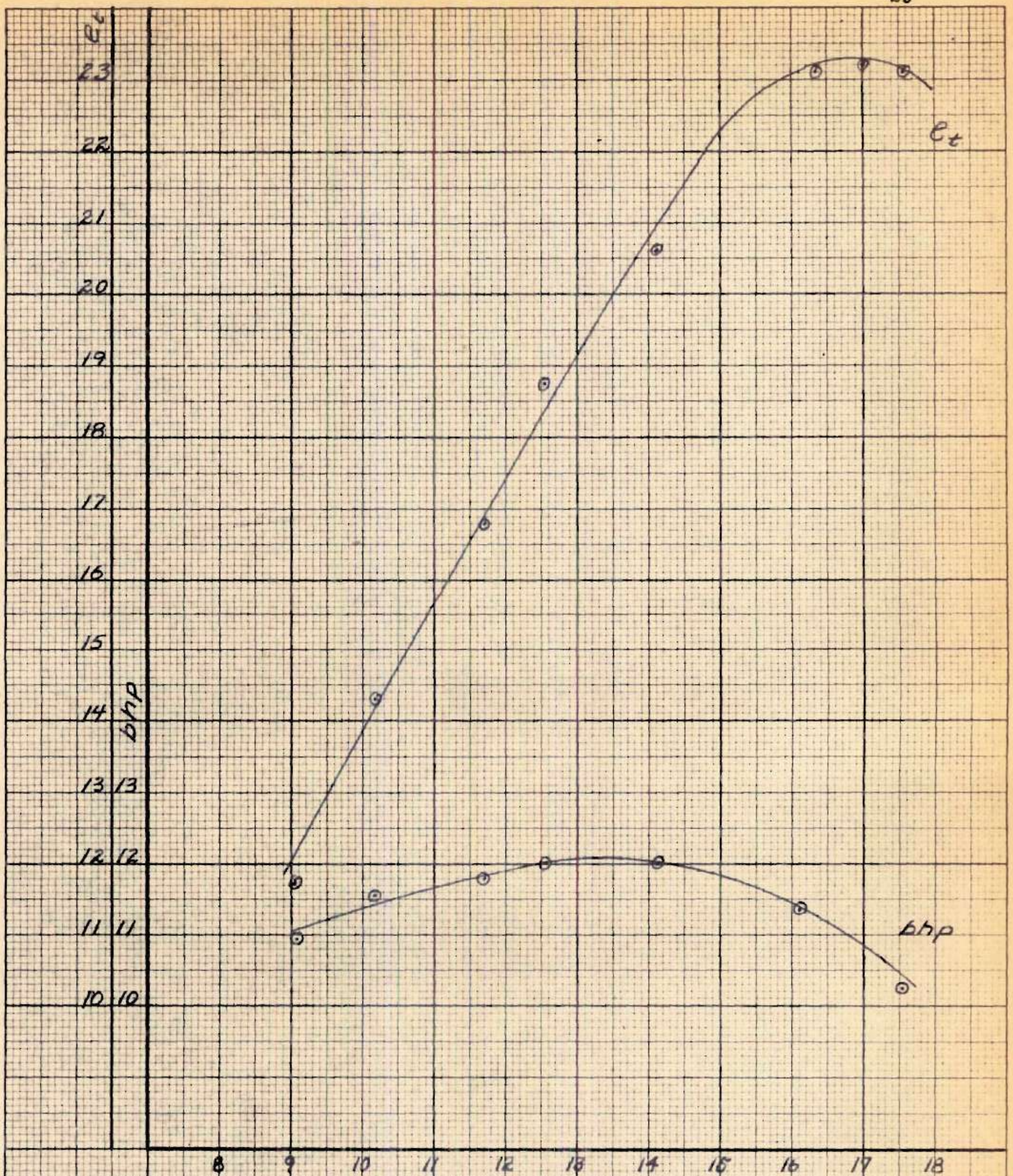


FIGURE 17
GASOLINE 1600 RPM
FULL THROTTLE

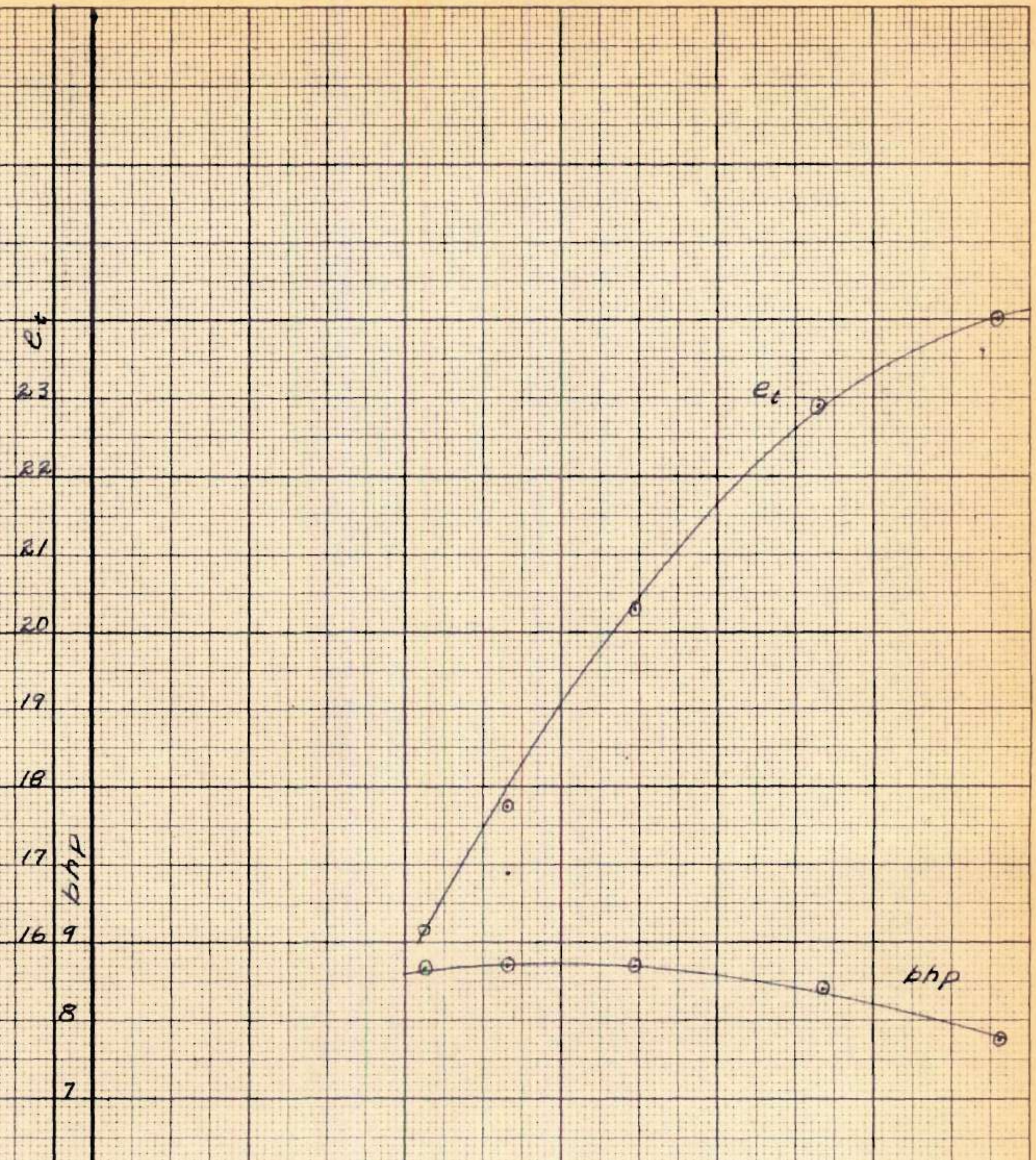


FIGURE 18
GASOLINE 1200 RPM
FULL THROTTLE

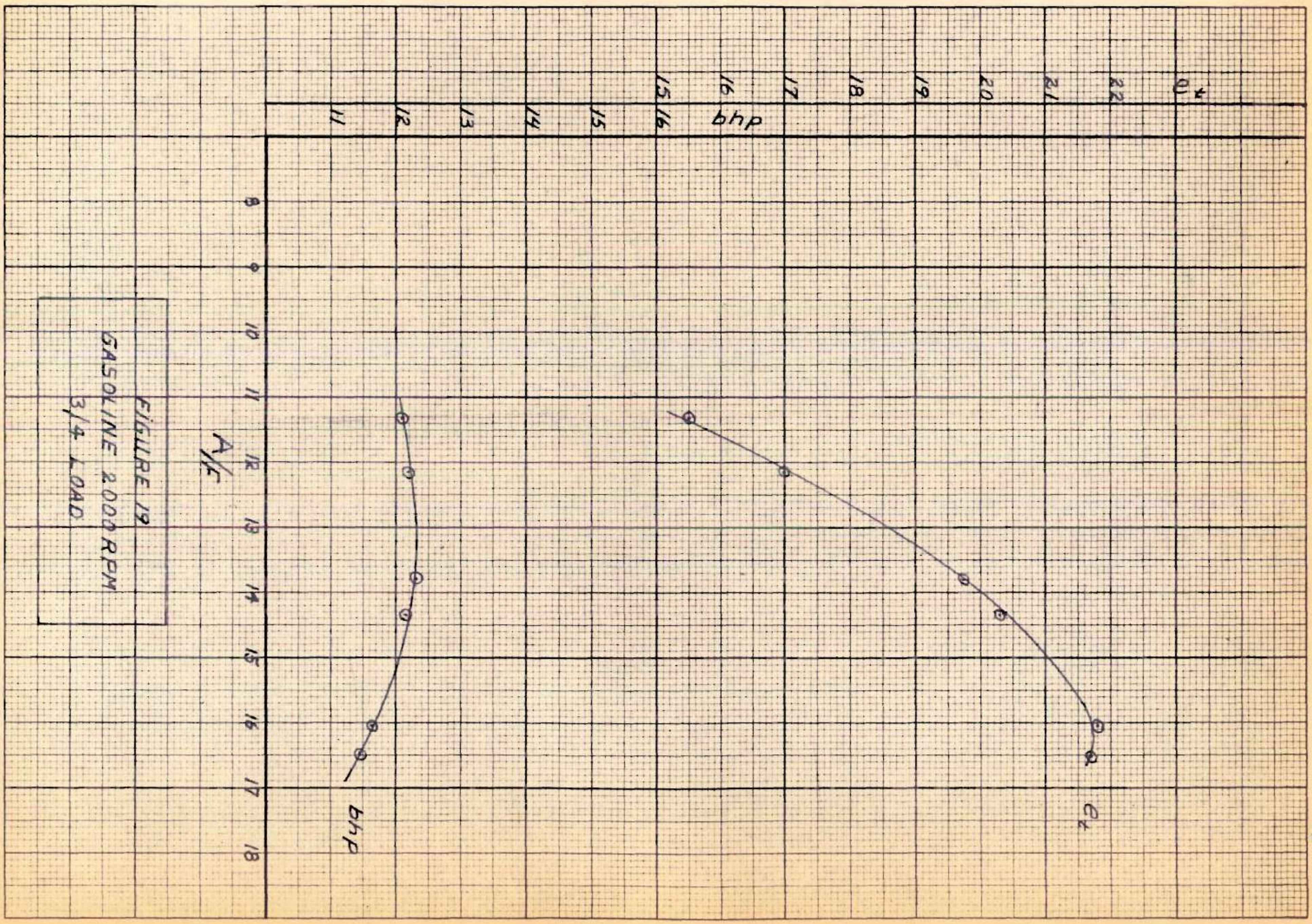


FIGURE 19
GASOLINE 2000 RPM
3/4 LOAD
A/F
bhp
e_t
8
9
10
11
12
13
14
15
16
17
18
11
12
13
14
15
16
15
16
17
18
19
20
21
22

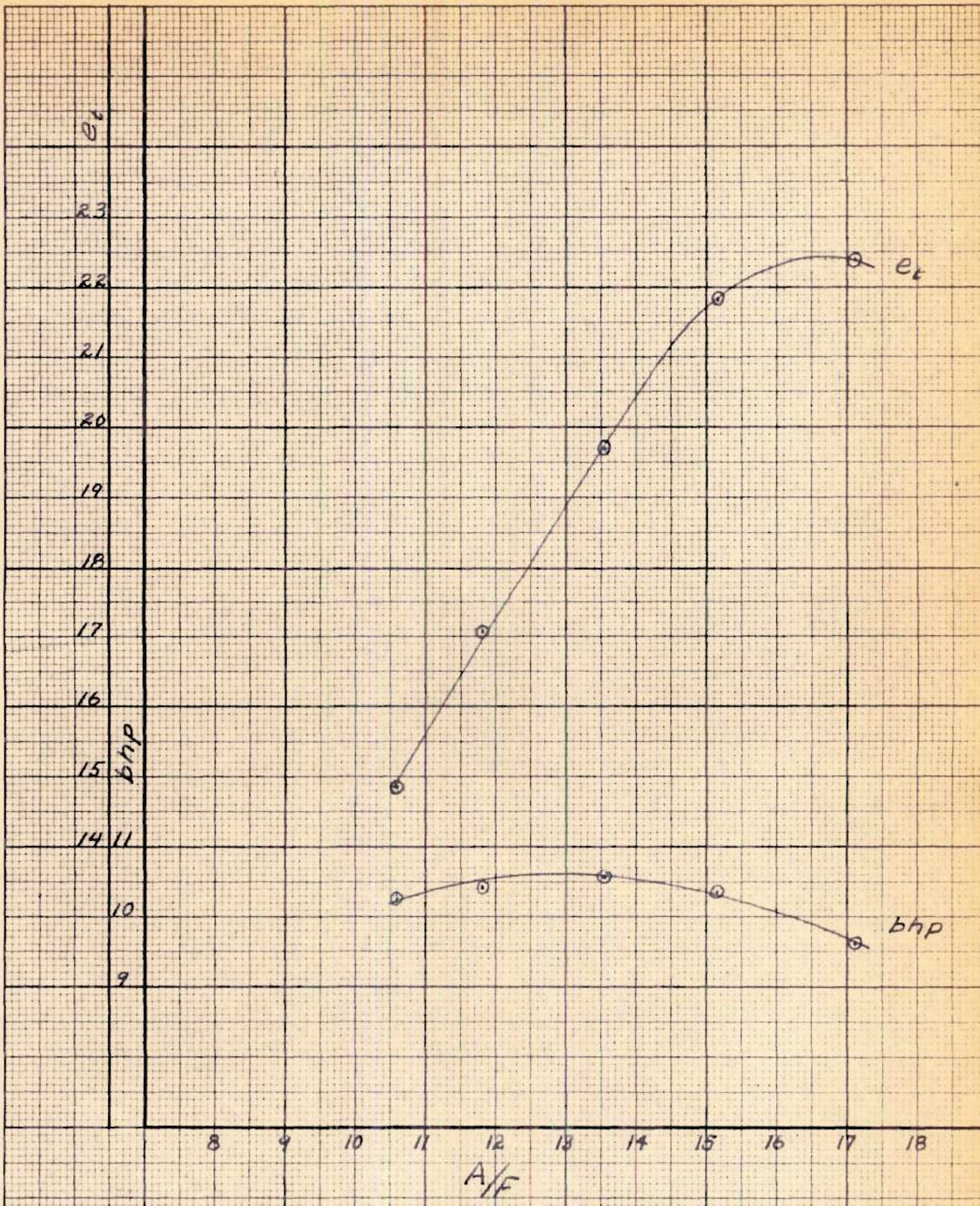


FIGURE 20
GASOLINE 1600 RPM
3/4 LOAD

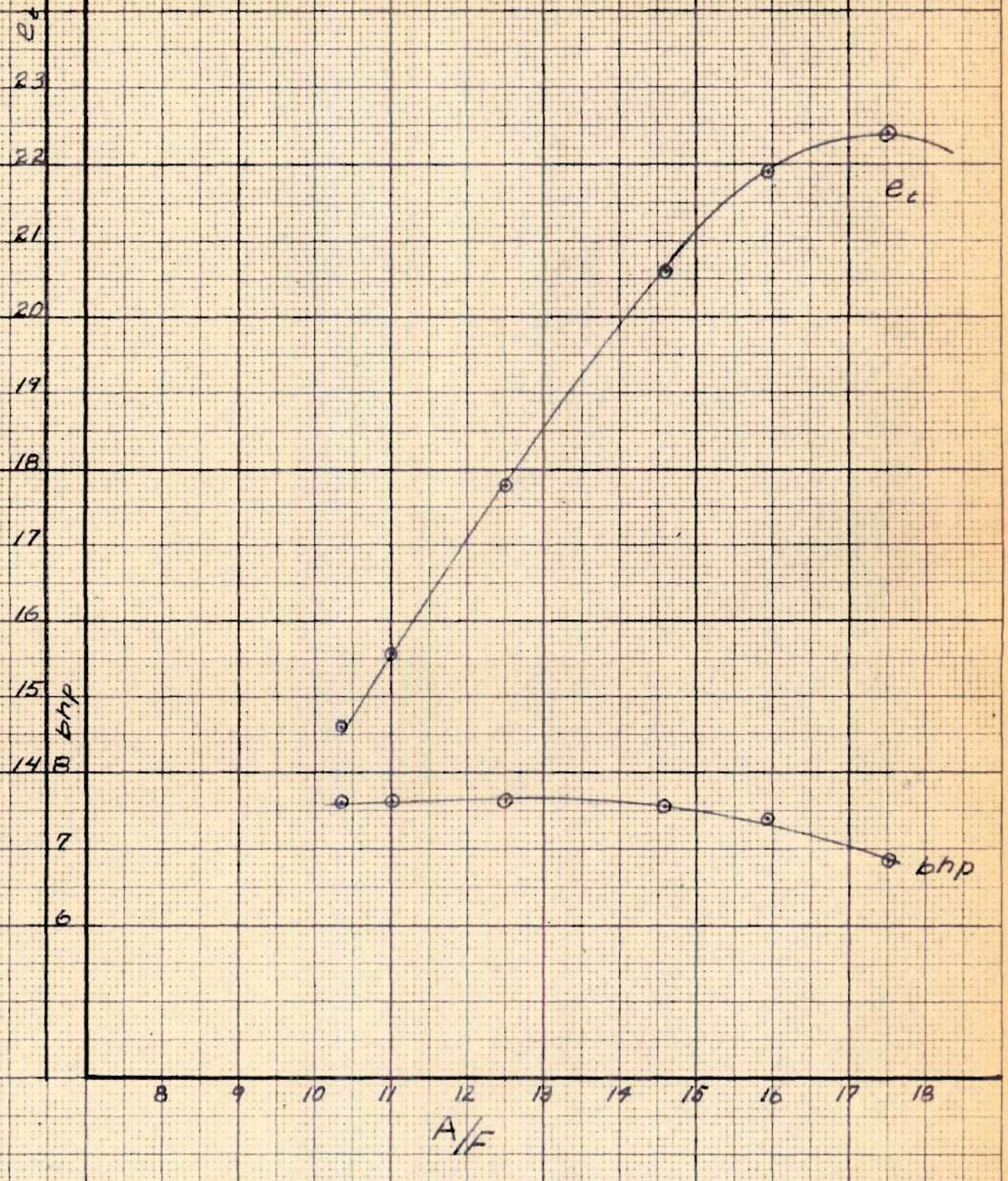


FIGURE 21
GASOLINE 1200 RPM
3/4 LOAD

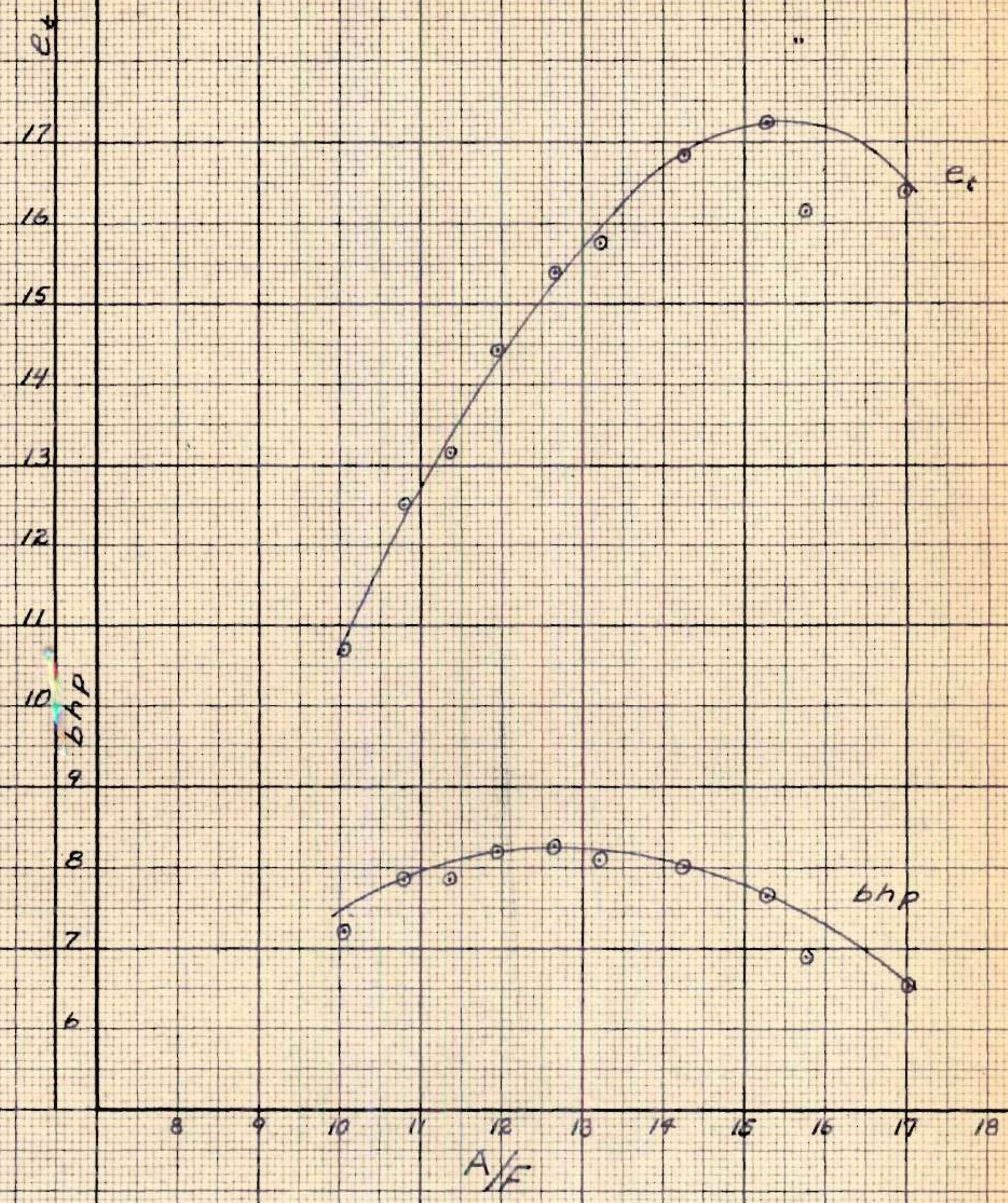


FIGURE 22
GASOLINE 2000 RPM
1/2 LOAD

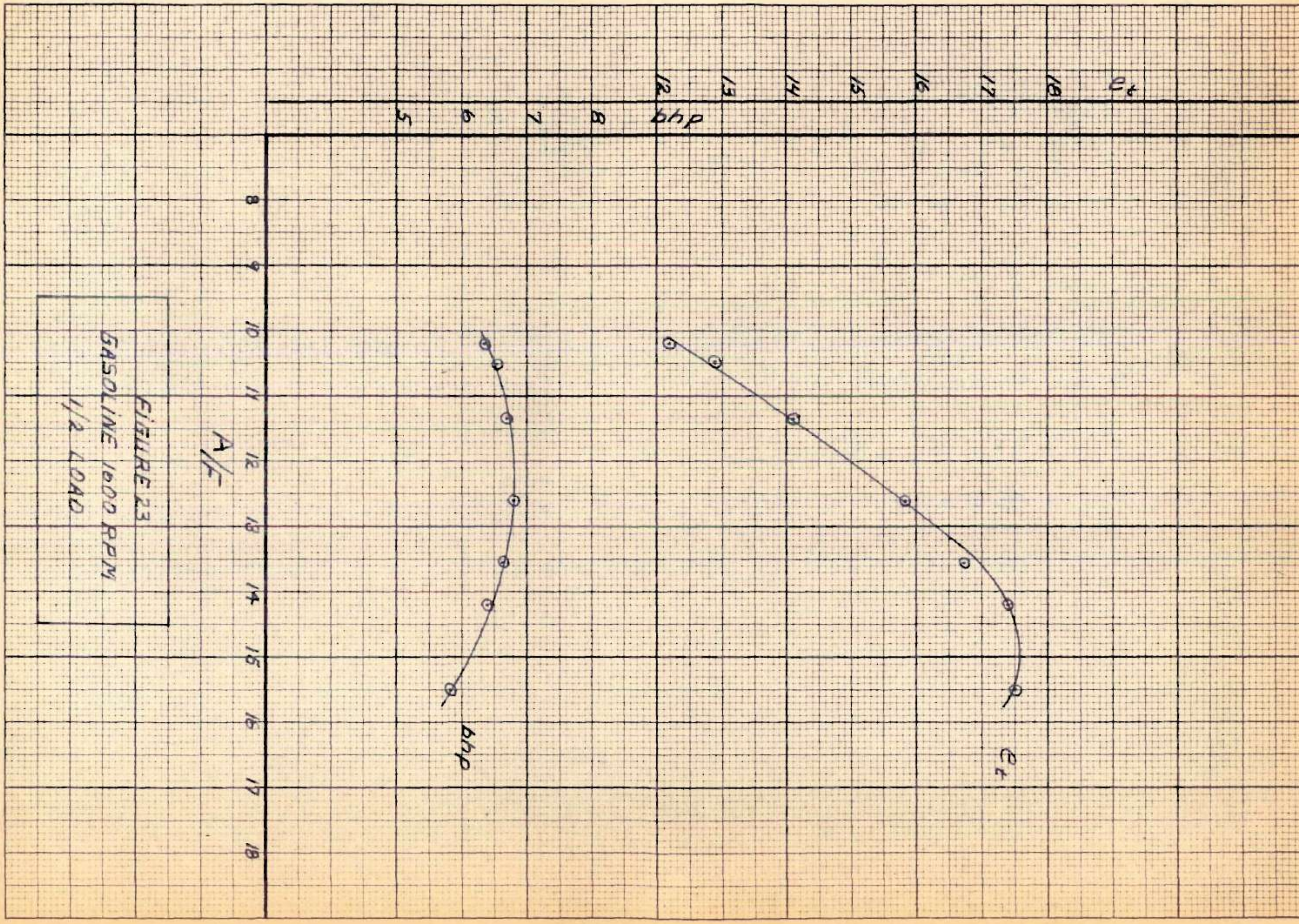


FIGURE 23
GASOLINE 1600 RPM
1/2 LOAD
A/F
bhp
e_t

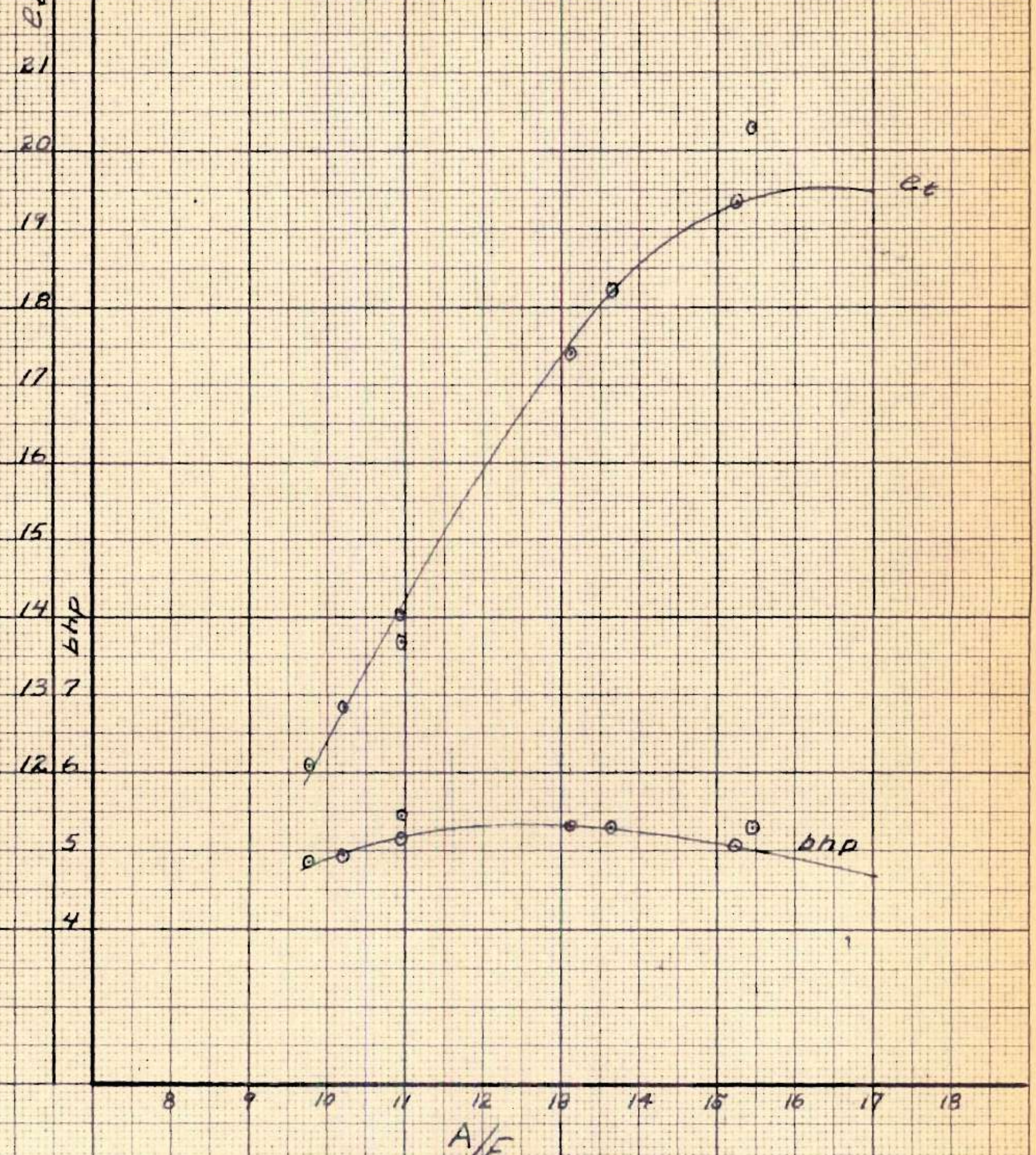


FIGURE 24
GASOLINE 1200 RPM
1/2 LOAD

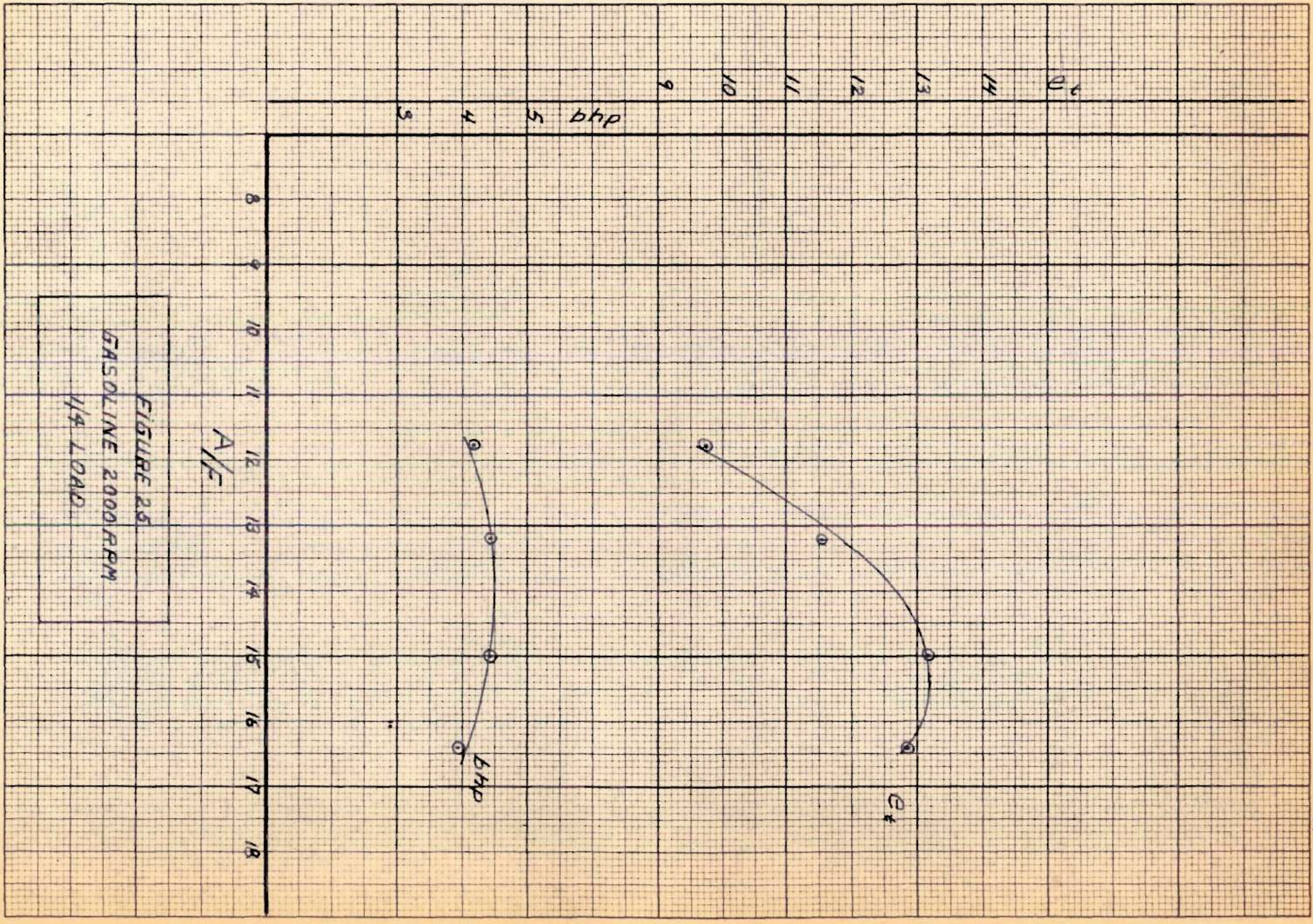


FIGURE 25
GASOLINE 2000 RPM
1/4 LOAD
A/F
8
9
10
11
12
13
14
15
16
17
18
3
4
5
bhp
9
10
11
12
13
14
e t
bhp
e t

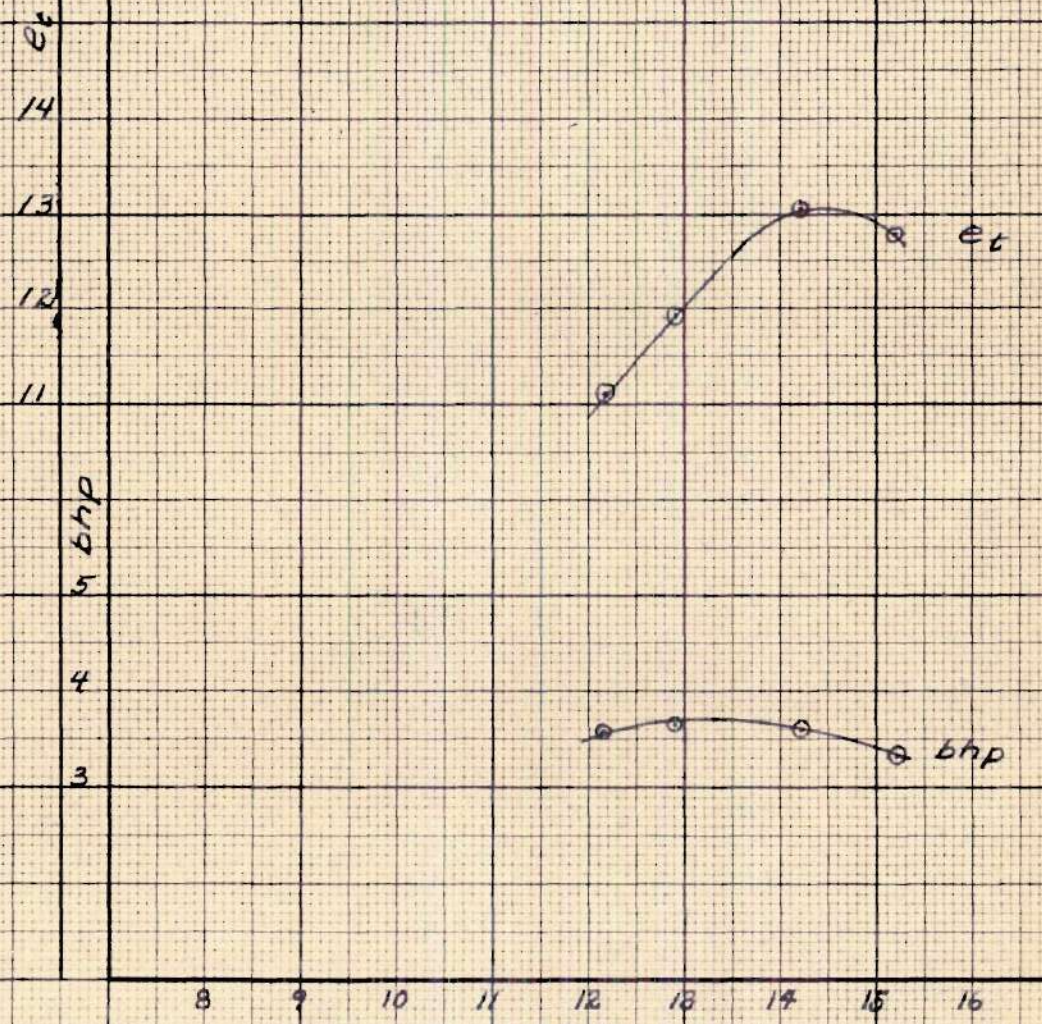


FIGURE 26
GASOLINE 1600 RPM
1/4 LOAD

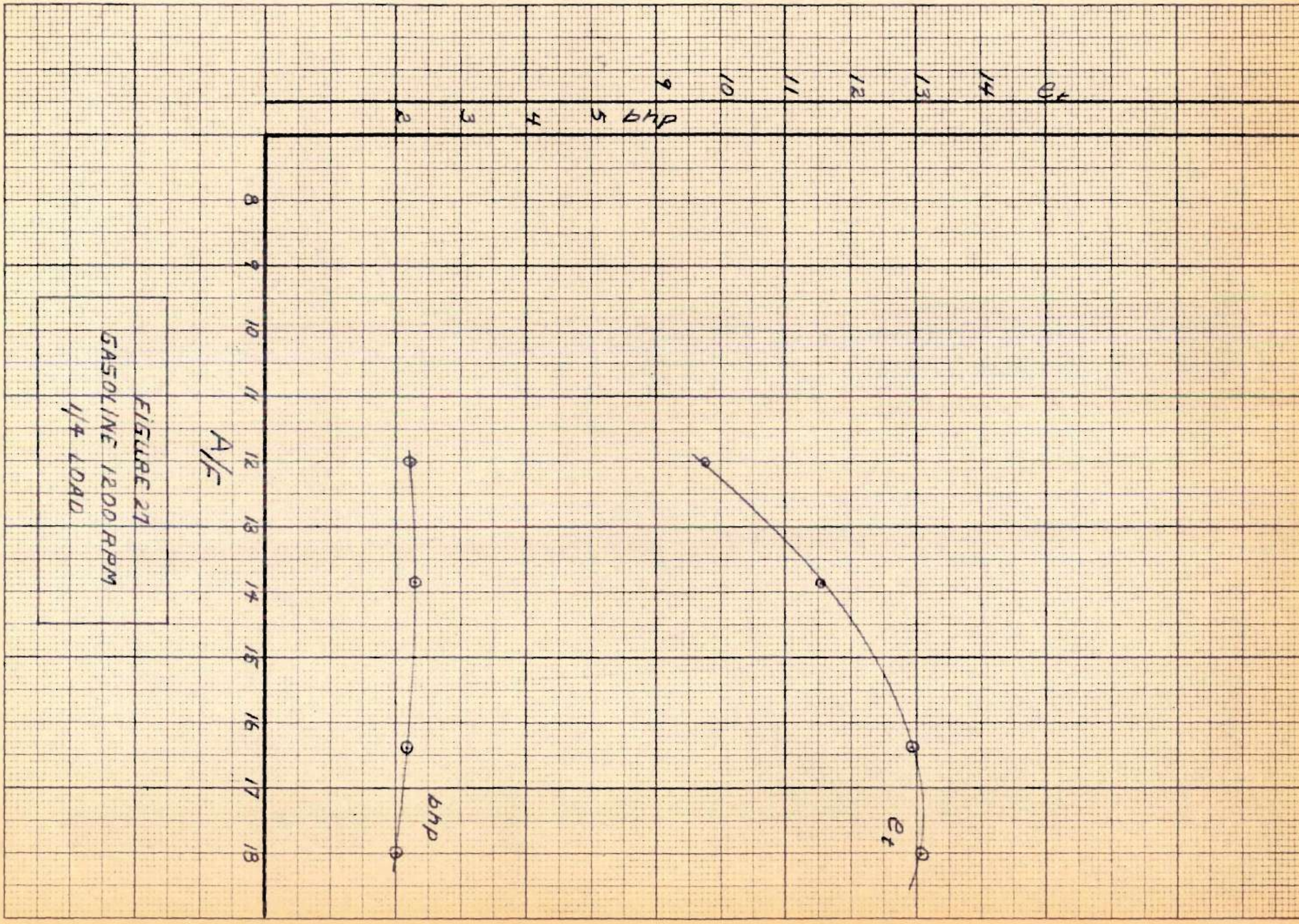


FIGURE 27
GASOLINE 1200 RPM
1/4 LOAD
A/F
8
9
10
11
12
13
14
15
16
17
18
bhp
2
3
4
5
9
10
11
12
13
14
e_t

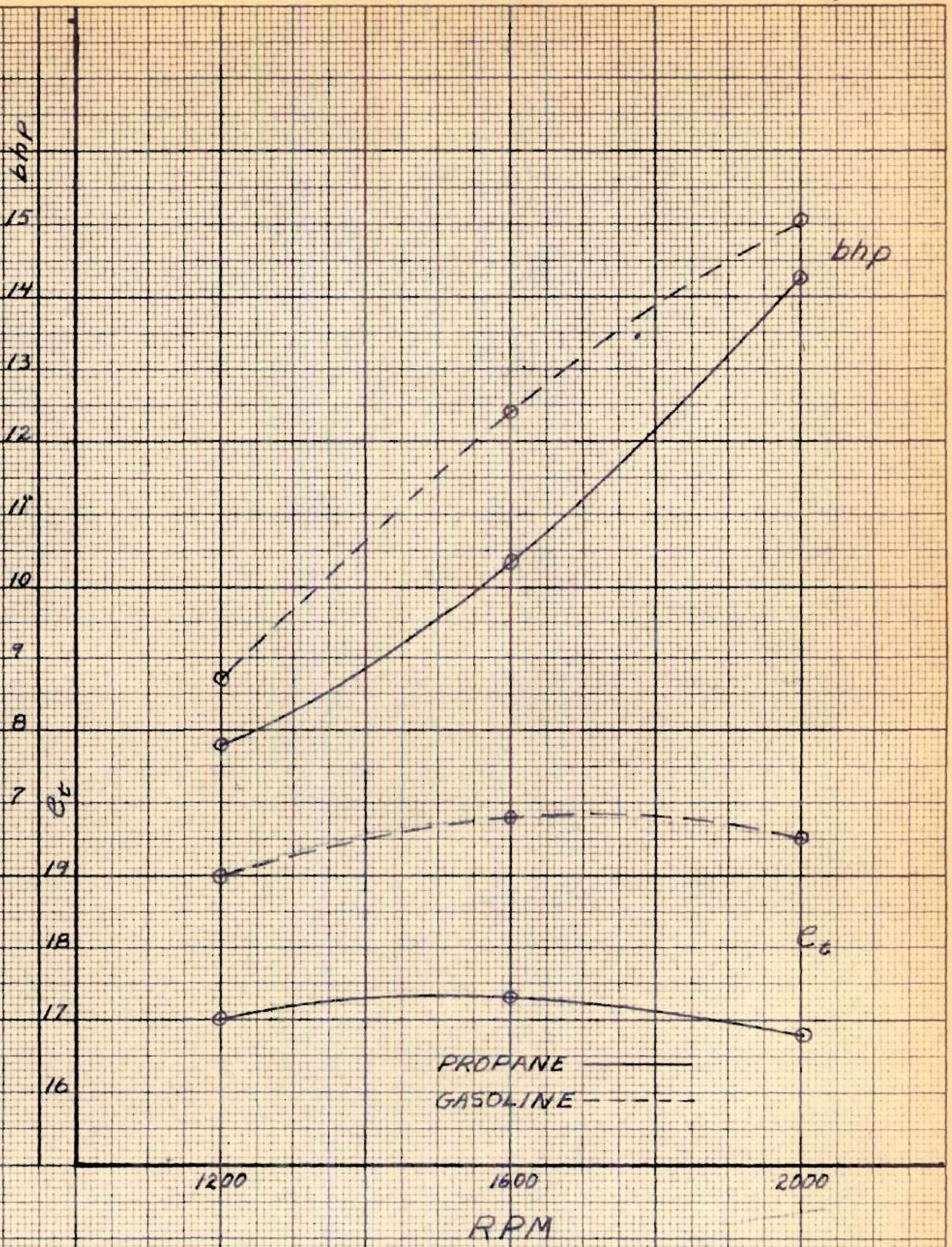


FIGURE 28
OPTIMUM VALUES
FULL THROTTLE

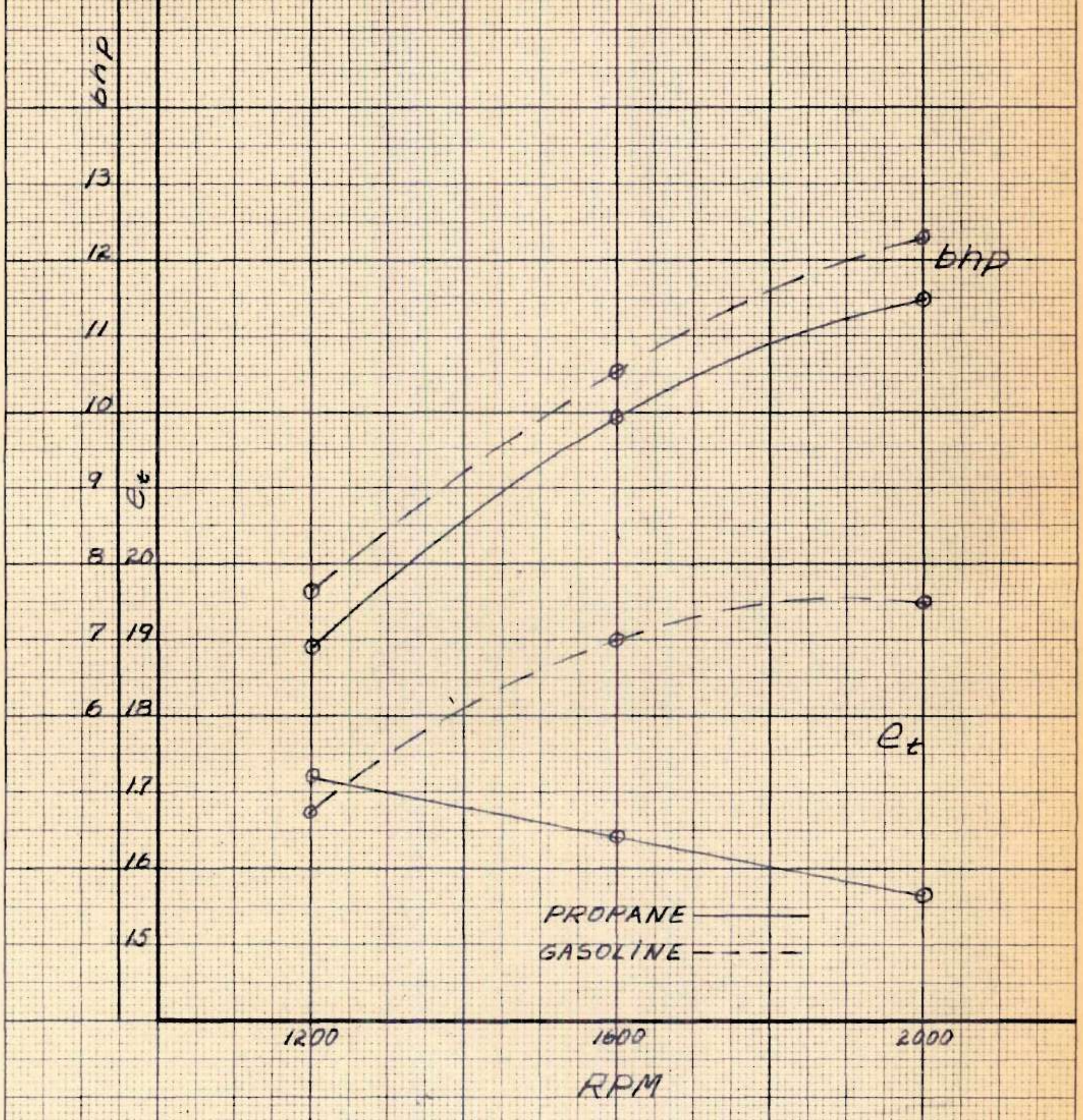


FIGURE 29
OPTIMUM VALUES
3/4 LOAD

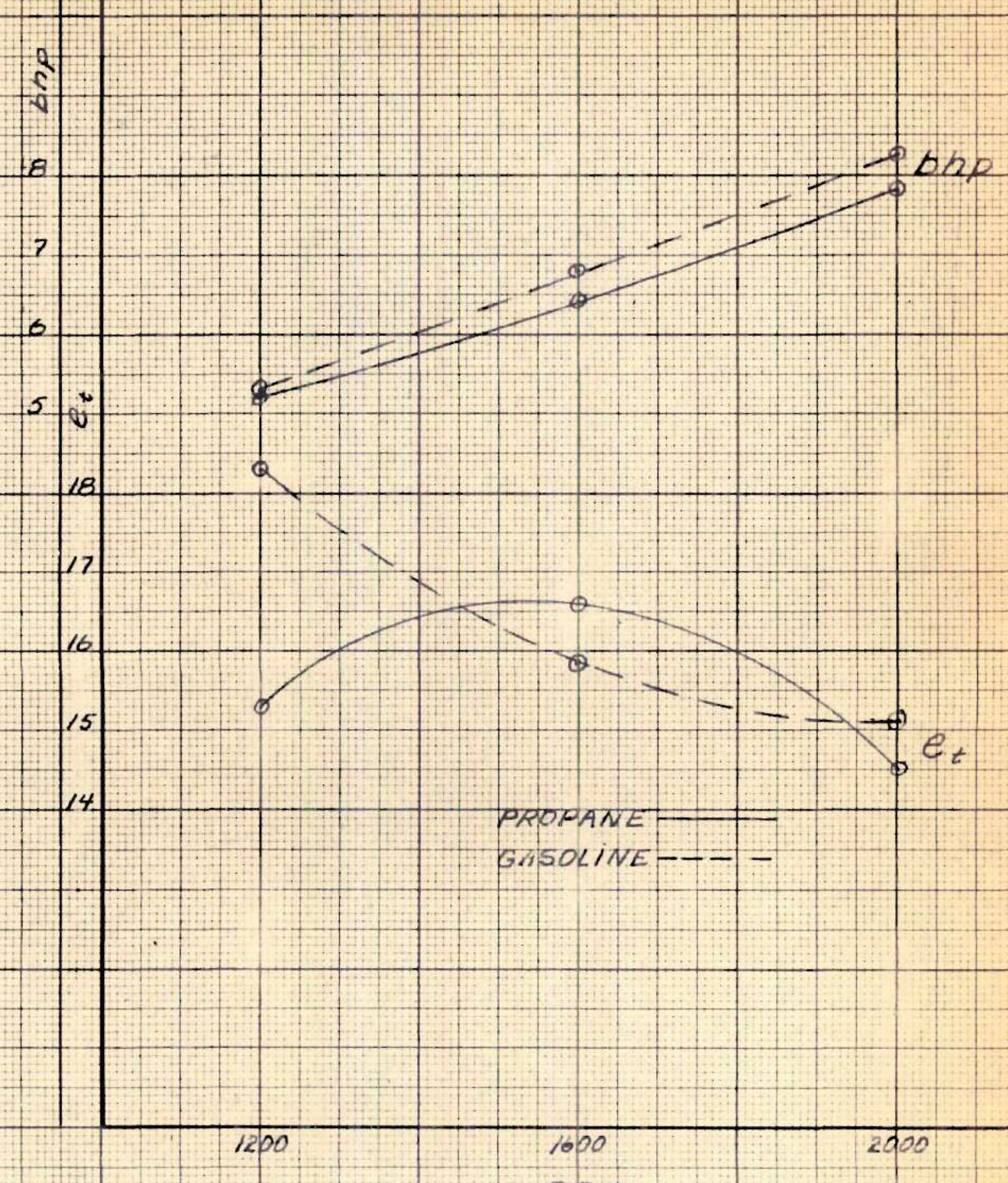


FIGURE 30
OPTIMUM VALUES
1/2 LOAD

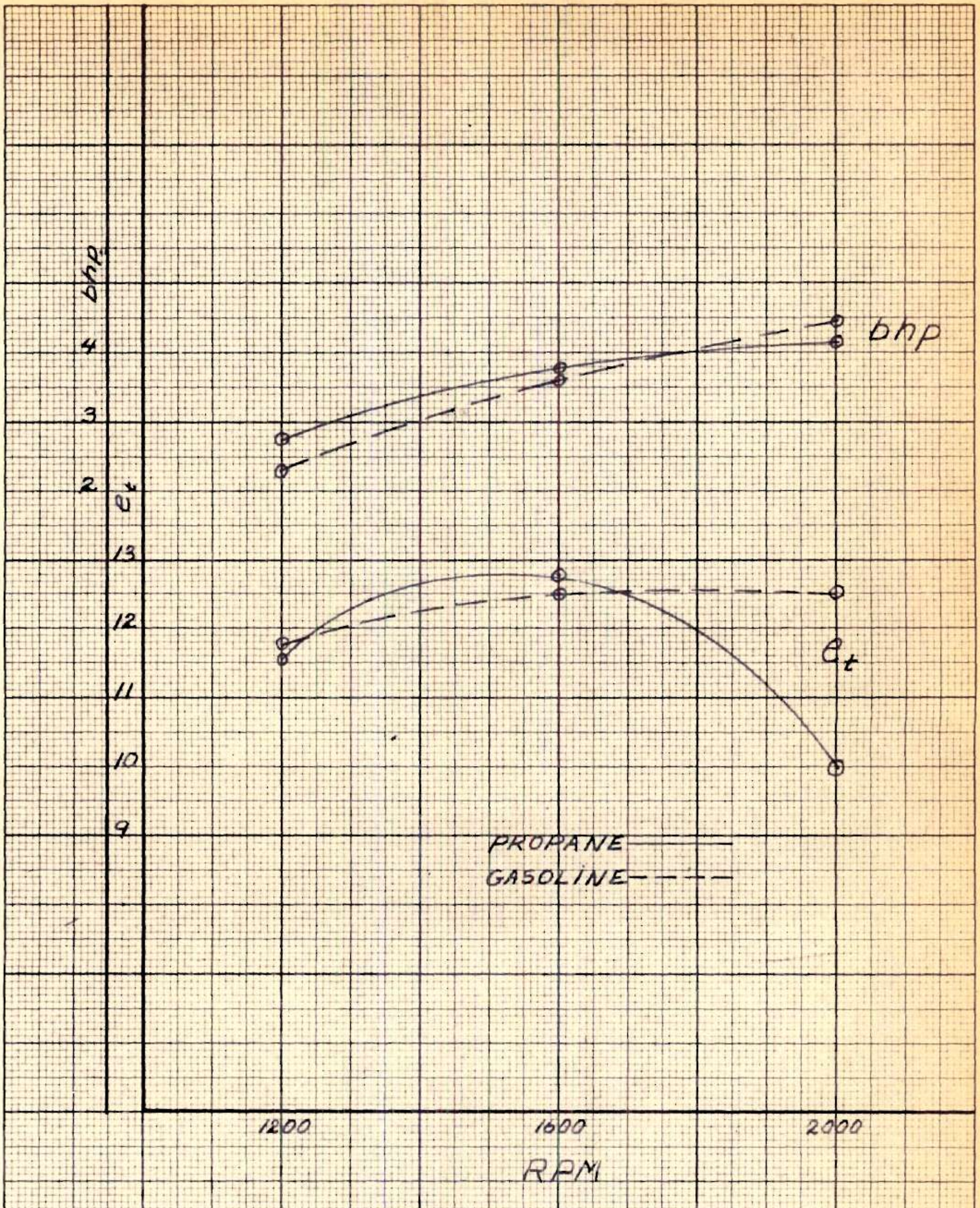


FIGURE 31
OPTIMUM VALUES
1/4 LOAD

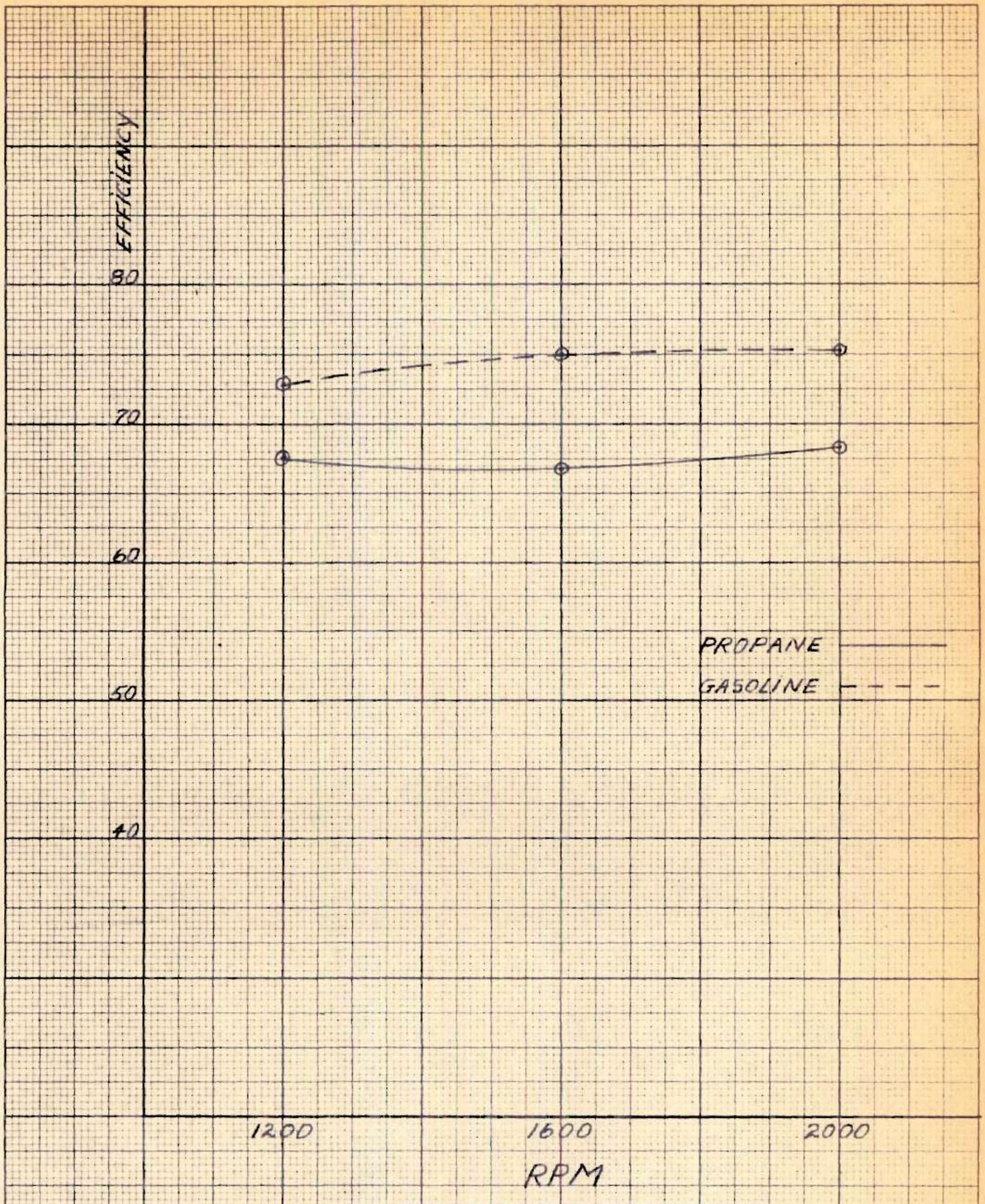


FIGURE 32
VOLUMETRIC EFFICIENCY
FULL THROTTLE

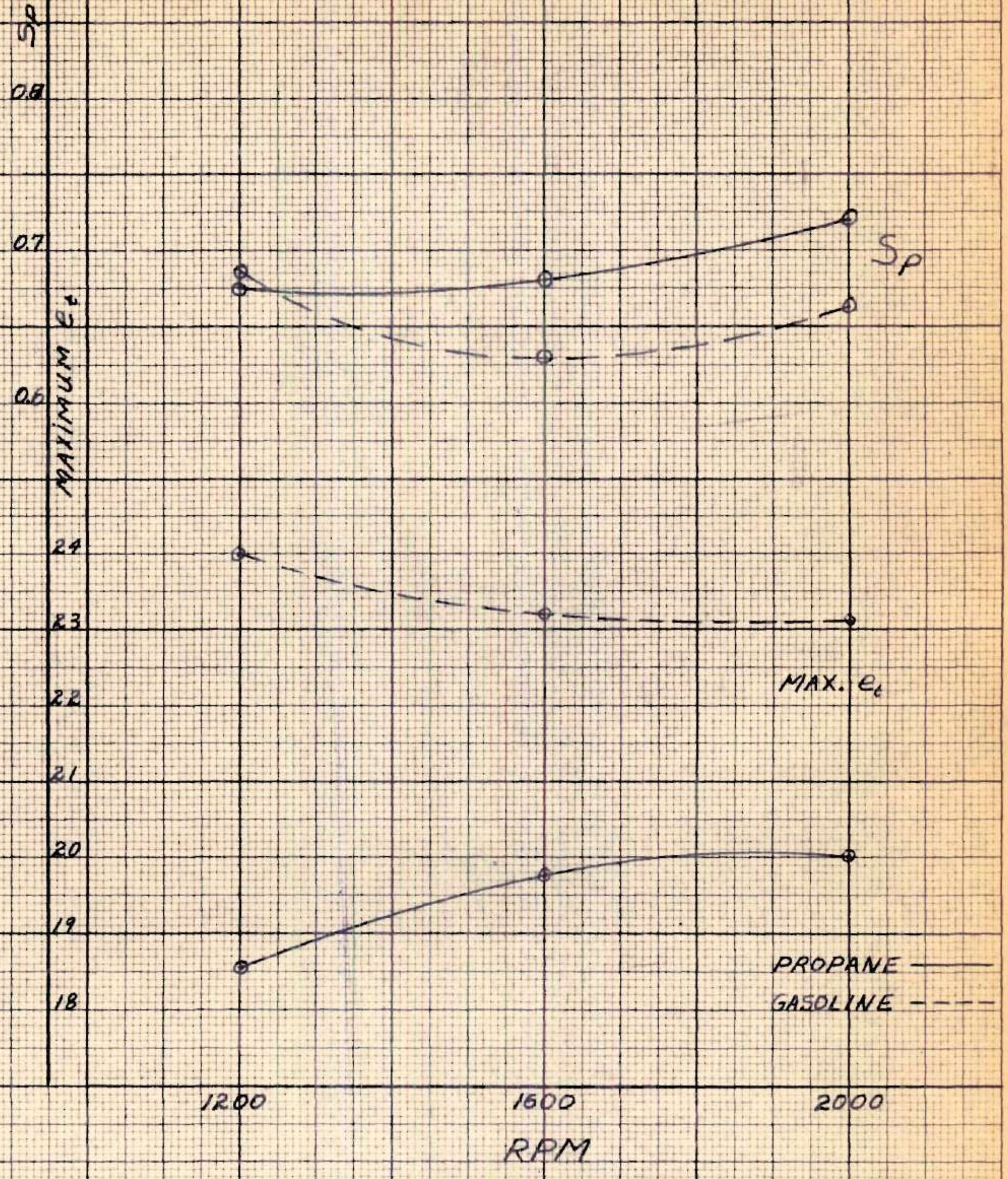


FIGURE 33
FULL THROTTLE

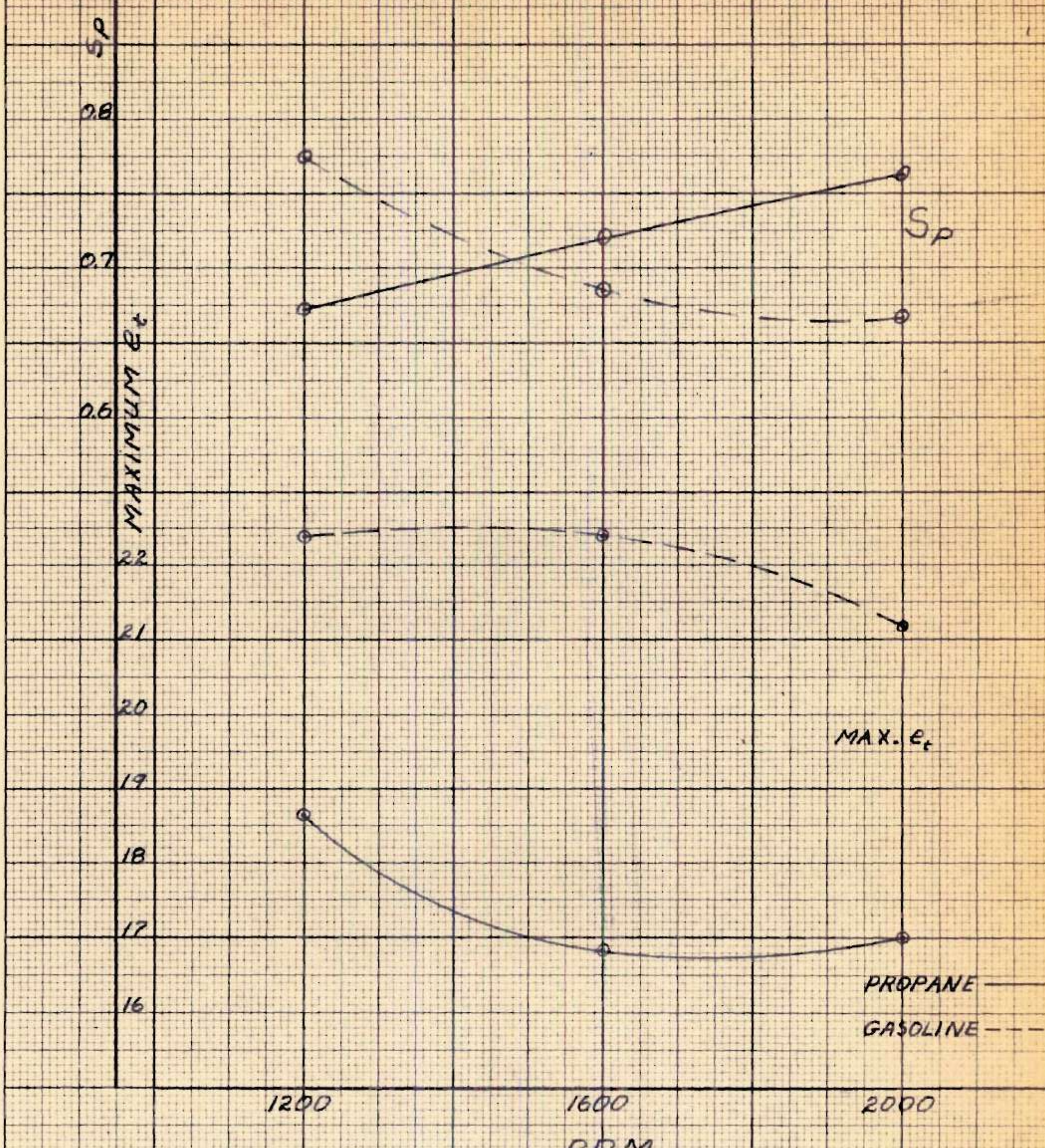


FIGURE 34
3/4 THROTTLE

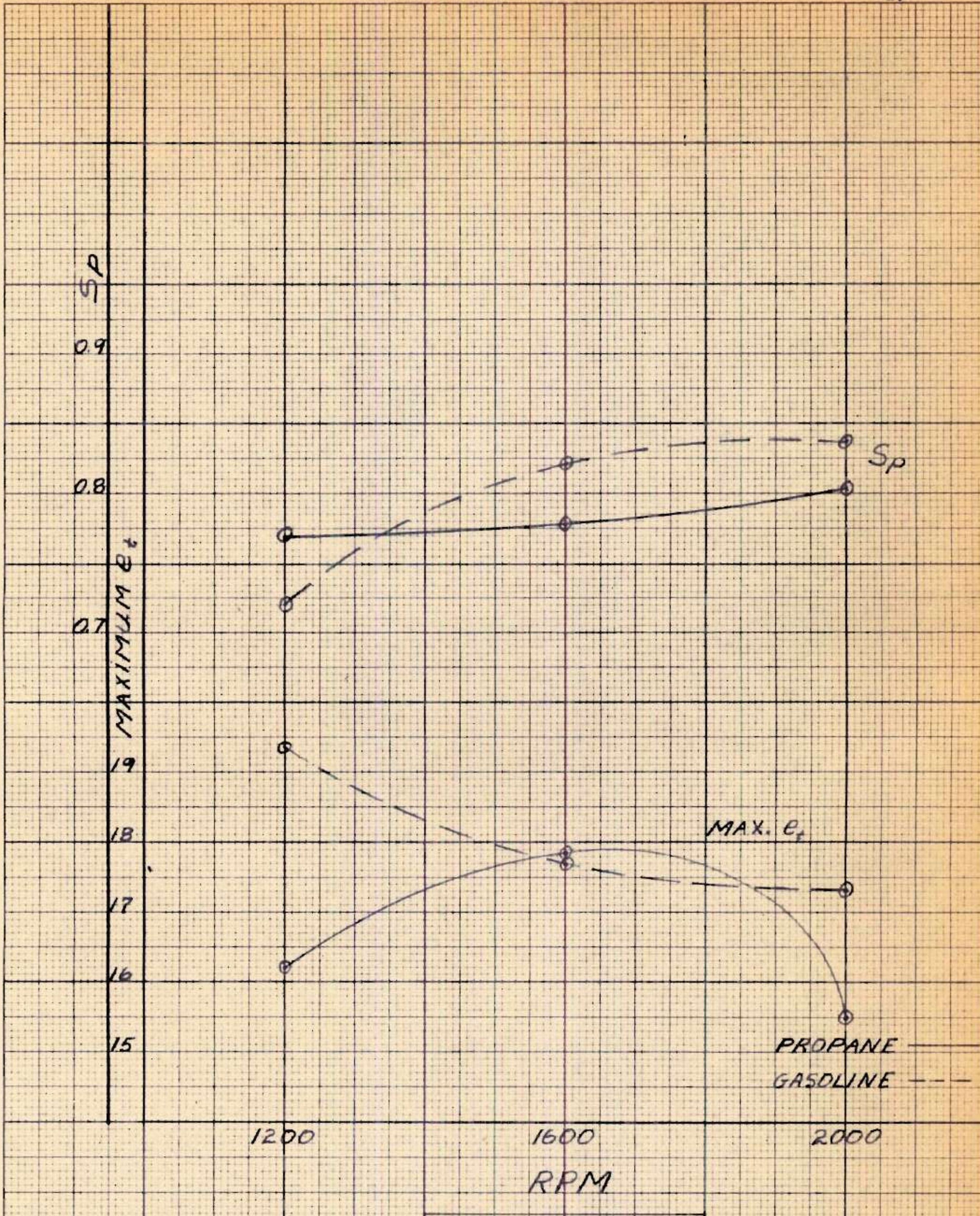


FIGURE 35
1/2 THROTTLE

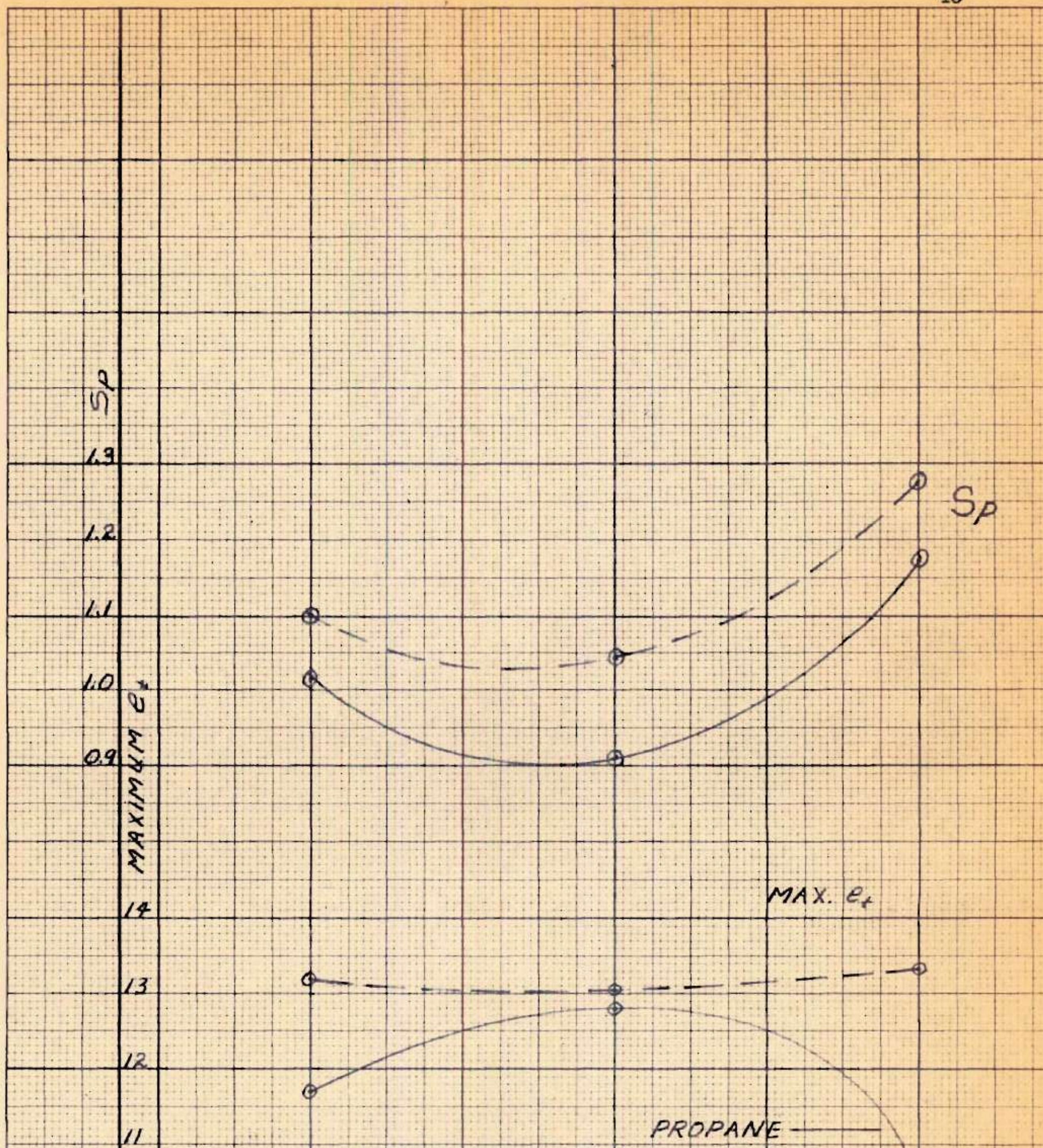


FIGURE 36

1/4 THROTTLE

APPENDIX II

TABLES

APPENDIX II

TABLE I OBSERVED DATA GROUP A FULL THROTTLE

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	79	4.35	40.0	23	37.50	82	28.25	28.95
2	81	4.35	40.8	23	37.50	82	28.25	28.95
3	84	4.35	41.1	23	37.50	82	28.25	28.95
4	87	4.35	41.8	23	37.50	82	28.25	28.95
5	94	4.30	42.2	23	37.50	82	28.25	28.95
6	105	4.20	42.7	23	37.00	82	28.25	28.94
7	110	4.20	42.3	23	37.00	82	28.25	28.94
8	116	4.20	41.2	24	36.75	83	28.25	28.92
9	125	4.20	40.2	24	36.75	83	28.25	28.92
10	128	4.30	39.5	25	36.75	83	28.25	28.92
11	130	4.40	38.5	25	36.75	83	28.25	28.92
12	132	4.45	37.7	27	36.50	83	28.25	28.92
13	136	4.45	36.5	27	36.50	83	28.25	28.92
14	140	4.50	34.5	27	36.50	83	28.25	28.92

OBSERVED DATA GROUP A 3/4 LOAD

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	104	3.05	33.4	28	39.50	88	25.00	29.38
2	105	3.05	34.0	28	39.50	88	25.00	29.38
3	107	3.05	34.2	28	39.50	88	25.00	29.38
4	112	3.05	34.6	27	39.50	88	25.00	29.38
5	114	3.10	34.5	27	38.75	88	25.00	29.38
6	118	3.10	34.7	27	38.50	88	25.00	29.38
7	126	3.10	34.6	27	38.50	88	25.00	29.38
8	131	3.10	34.0	27	38.50	89	25.00	29.38
9	136	3.10	32.9	27	38.25	89	25.00	29.38
10	142	3.10	30.5	27	38.00	89	25.00	29.38
11	150	3.15	28.8	27	38.00	89	25.00	29.38
12	156	3.20	25.9	27	38.00	89	25.00	29.38

TABLE I OBSERVED DATA GROUP A (Continued) 1/2 LOAD

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	155	1.80	23.5	28	37.75	89	20	29.38
2	88	1.80	23.6	28	37.75	89	20	29.38
3	76	1.80	23.3	28	37.50	89	20	29.38
4	87	1.80	22.8	28	37.50	89	20	29.38
5	91	1.80	21.7	28	37.50	89	20	29.38
6	95	1.80	20.5	28	37.50	89	20	29.38
7	100	1.85	19.1	28	37.50	89	20	29.38
8	106	1.85	16.4	28	37.50	89	20	29.38

OBSERVED DATA GROUP A 1/4 LOAD

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	94	1.00	11.7	28	37.25	89	15	29.38
2	95	1.00	12.0	28	37.25	89	15	29.38
3	98	1.00	12.1	28	37.25	89	15	29.38
4	100	1.00	12.4	28	37.25	89	15	29.38
5	102	1.00	12.3	28	37.25	89	15	29.38
6	107	1.00	12.3	28	37.25	89	15	29.38
7	112	1.00	11.9	28	37.25	89	15	29.38
8	122	1.00	10.6	28	37.25	89	15	29.38
9	138	1.00	8.7	28	37.25	89	15	29.38

TABLE II OBSERVED DATA GROUP B FULL THROTTLE

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	165	2.60	38.7	28	38.00	88	28.92	29
2	141	2.60	38.8	28	38.00	88	28.92	29
3	132	2.60	38.5	28	38.00	88	28.92	29
4	115	2.60	37.4	28	38.00	88	28.92	29
5	90	2.75	32.2	28	38.00	88	29.35	29
6	89	2.75	33.6	28	37.50	87	29.35	29
7	85	2.75	35.3	28	37.50	87	29.35	29

OBSERVED DATA GROUP B 3/4 LOAD

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	118	2.3	35.2	25	38.75	86	26.25	29
2	116	2.3	36.2	25	38.50	87	26.25	29
3	130	2.3	36.5	25	38.50	87	26.25	29
4	134	2.3	37.2	25	38.50	87	26.25	29
5	142	2.3	37.3	25	38.50	87	26.25	29
6	155	2.3	37.3	25	38.50	87	26.25	29
7	166	2.3	37.3	25	38.50	87	26.25	29

TABLE II OBSERVED DATA GROUP B (Continued) 1/2 LOAD

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	258	1.35	22.6	26	38.5	88	20.5	28.94
2	246	1.35	23.7	26	38.5	88	20.5	28.94
3	230	1.30	24.0	26	38.5	88	20.5	28.94
4	220	1.30	24.0	26	38.5	88	20.5	28.94
5	210	1.30	23.8	26	38.5	88	20.5	28.94

OBSERVED DATA GROUP B 1/4 LOAD

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	316	0.8	12.4	28	38.40	88	16.5	28.94
2	300	0.8	12.8	28	38.30	88	16.5	28.94
3	294	0.8	13.1	28	38.25	88	16.5	28.94
4	290	0.8	14.2	28	38.25	88	16.5	28.94
5	278	0.8	14.0	28	38.25	88	16.5	28.94
6	267	0.8	13.7	28	38.25	88	16.5	28.94

TABLE III OBSERVED DATA GROUP C FULL THROTTLE

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	171	1.50	39.0	28	38.00	89	28.5	28.90
2	182	1.50	39.2	28	38.00	89	28.5	28.90
3	196	1.50	39.2	28	38.00	89	28.5	28.90
4	215	1.50	38.1	27	39.50	92	30.0	29.38
5	213	1.50	37.8	28	38.00	89	28.5	28.90
6	226	1.45	36.0	28	39.50	92	30.0	29.38
7	244	1.45	34.0	28	39.50	92	30.0	29.38

OBSERVED DATA GROUP C 3/4 LOAD

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	199	1.15	34.6	28	37.50	87	25.0	28.90
2	209	1.15	34.7	28	37.50	87	25.0	28.90
3	212	1.15	34.7	28	37.50	87	25.0	28.90
4	218	1.15	34.7	28	37.50	87	25.0	28.90
5	227	1.15	34.3	28	37.50	87	25.0	28.90
6	254	1.15	32.2	32	39.00	94	25.0	29.38
7	264	1.20	30.2	31	39.25	93	25.0	29.38

TABLE III OBSERVED DATA GROUP C (Continued) 1/2 LOAD

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	292	0.75	23.3	28	37.5	86	21	28.9
2	272	0.75	25.3	28	37.5	86	21	28.9
3	260	0.75	25.9	28	37.5	86	21	28.9
4	244	0.75	25.9	28	37.5	86	21	28.9
5	230	0.75	25.6	28	37.5	86	21	28.9

OBSERVED DATA GROUP C 1/4 LOAD

Run	t	h_w	L	t_g	P_p	t_a	MP	BP
1	394	0.4	12.0	28	37.25	85	16	28.9
2	386	0.4	12.4	28	37.25	85	16	28.9
3	374	0.4	13.0	28	37.25	85	16	28.9
4	363	0.4	13.7	28	37.25	85	16	28.9
5	354	0.4	13.7	28	37.25	85	16	28.9
6	316	0.4	13.0	28	37.25	85	16	28.9

TABLE IV CALCULATED DATA GROUP A FULL THROTTLE

Run	q_p	w_p	Q	A/F	bhp	e_t
1	1.860	0.2180	2.070	9.50	13.33	12.10
2	1.812	0.2120	2.070	9.76	13.60	12.60
3	1.750	0.2050	2.070	10.10	13.70	13.20
4	1.690	0.1978	2.070	10.45	13.90	13.85
5	1.560	0.1830	2.050	11.20	14.08	15.20
6	1.380	0.1635	2.035	12.45	14.23	17.35
7	1.316	0.1560	2.035	13.05	14.10	18.05
8	1.229	0.1425	2.035	14.30	13.74	18.85
9	1.140	0.1322	2.035	15.35	13.40	19.75
10	1.108	0.1290	2.050	15.90	13.16	19.95
11	1.091	0.1270	2.080	16.40	12.82	19.75
12	1.062	0.1235	2.095	16.95	12.55	19.80
13	1.031	0.1200	2.095	17.45	12.15	19.80
14	0.991	0.1153	2.105	18.30	11.50	19.50

CALCULATED DATA GROUP A 3/4 LOAD

Run	q_p	w_p	Q	A/F	bhp	e_t
1	1.458	0.1700	1.738	10.20	11.10	12.80
2	1.442	0.1680	1.738	10.34	11.33	13.20
3	1.417	0.1650	1.738	10.50	11.43	13.55
4	1.358	0.1583	1.738	10.95	11.53	14.30
5	1.310	0.1520	1.750	11.50	11.50	14.75
6	1.256	0.1460	1.750	12.00	11.57	15.50
7	1.177	0.1370	1.750	12.78	11.52	16.45
8	1.131	0.1315	1.750	13.30	11.33	16.85
9	1.082	0.1260	1.750	13.90	10.95	17.00
10	1.031	0.1195	1.750	14.65	10.15	16.55
11	0.975	0.1134	1.760	15.50	9.60	16.55
12	0.937	0.1087	1.790	16.50	8.63	15.50

TABLE IV CALCULATED DATA GROUP A (Continued) 1/2 LOAD

Run	q_p	w_p	Q	A/F	bhp	e_t
1	0.931	0.1085	1.335	12.30	7.83	14.10
2	0.904	0.1050	1.335	12.70	7.85	14.60
3	0.865	0.1005	1.335	13.30	7.77	15.10
4	0.826	0.0962	1.335	13.85	7.60	15.45
5	0.790	0.0920	1.335	14.50	7.24	15.40
6	0.757	0.0881	1.335	15.15	6.84	15.20
7	0.719	0.0836	1.354	16.20	6.37	14.90

CALCULATED DATA GROUP A 1/4 LOAD

Run	q_p	w_p	Q	A/F	bhp	e_t
1	0.760	0.0885	0.996	11.25	3.90	8.63
2	0.751	0.0875	0.996	11.40	4.00	8.95
3	0.729	0.0847	0.996	11.75	4.08	9.40
4	0.714	0.0830	0.996	12.00	4.13	9.73
5	0.700	0.0814	0.996	12.25	4.10	9.85
6	0.667	0.0775	0.996	12.85	4.10	10.35
7	0.638	0.0743	0.996	13.40	3.97	10.45
8	0.585	0.0681	0.996	14.60	3.53	10.15

TABLE V CALCULATED DATA GROUP B FULL THROTTLE

Run	q_p	w_p	Q	A/F	bhp	e_t
1	0.800	0.0929	1.620	17.45	8.59	18.05
2	0.810	0.0938	1.620	17.30	8.96	18.60
3	0.847	0.0985	1.620	16.45	9.41	18.70
4	0.876	0.1030	1.595	15.50	10.30	19.75
5	1.035	0.1200	1.595	13.30	10.35	16.82
6	1.105	0.1285	1.595	12.40	10.27	15.60
7	1.270	0.1475	1.595	10.80	9.97	13.20

CALCULATED DATA GROUP B 3/4 LOAD

Run	q_p	w_p	Q	A/F	bhp	e_t
1	1.292	0.1513	1.500	9.92	9.40	12.20
2	1.270	0.1485	1.500	10.10	9.60	12.70
3	1.153	0.1350	1.500	11.10	9.75	14.20
4	1.072	0.1255	1.500	11.95	9.90	15.50
5	1.057	0.1235	1.500	12.15	9.95	15.85
6	0.994	0.1163	1.500	12.90	9.95	16.85
7	0.945	0.1105	1.500	13.55	9.35	16.65

TABLE V CALCULATED DATA GROUP B (Continued) 1/2 LOAD

Run	q_p	w_p	Q	A/F	bhp	e_t
1	0.576	0.0670	1.150	17.20	6.03	17.55
2	0.605	0.0740	1.150	15.55	6.32	17.60
3	0.648	0.0752	1.128	15.00	6.40	16.60
4	0.675	0.0786	1.128	14.35	6.40	15.95
5	0.709	0.0824	1.128	13.70	6.35	15.10

CALCULATED DATA GROUP B 1/4 LOAD

Run	q_p	w_p	Q	A/F	bhp	e_t
1	0.465	0.0540	0.833	15.40	3.31	11.95
2	0.490	0.0569	0.833	14.65	3.41	11.70
3	0.499	0.0580	0.833	14.35	3.79	12.80
4	0.506	0.0589	0.833	14.10	3.73	12.40
5	0.529	0.0615	0.833	13.50	3.65	11.60
6	0.550	0.0643	0.833	12.95	3.49	10.65

TABLE VI CALCULATED DATA GROUP C FULL THROTTLE

Run	q_p	w_p	Q	A/F	bhp	e_t
1	0.864	0.1010	1.210	12.00	7.80	15.20
2	0.807	0.0945	1.210	12.80	7.83	16.30
3	0.745	0.0871	1.210	13.90	7.83	17.65
4	0.707	0.0828	1.210	14.60	7.62	18.10
5	0.685	0.0802	1.210	15.10	7.56	18.55
6	0.664	0.0777	1.210	15.55	7.30	18.50
7	0.621	0.0727	1.210	16.65	6.80	18.40

CALCULATED DATA GROUP C 3/4 LOAD

Run	q_p	w_p	Q	A/F	bhp	e_t
1	0.745	0.0871	1.070	12.30	6.90	15.60
2	0.724	0.0847	1.070	13.05	6.92	16.10
3	0.689	0.0806	1.070	13.70	6.94	16.90
4	0.679	0.0794	1.070	13.95	6.94	17.20
5	0.634	0.0741	1.070	14.90	6.86	18.20
6	0.580	0.0679	1.088	16.05	6.44	18.65
7	0.565	0.0660	1.088	16.50	6.04	17.95
8	0.509	0.0595	1.088	18.60	5.10	16.85

TABLE VI CALCULATED DATA GROUP C (Continued) 1/2 LOAD

Run	q_p	w_p	Q	A/F	bhp	e_t
1	0.494	0.0577	0.873	15.10	4.66	15.90
2	0.528	0.0617	0.873	14.10	5.06	16.15
3	0.554	0.0648	0.873	13.50	5.18	15.70
4	0.590	0.0690	0.873	12.65	5.18	14.75
5	0.525	0.0721	0.873	12.10	5.12	13.80

CALCULATED DATA GROUP C 1/4 LOAD

Run	q_p	w_p	Q	A/F	bhp	e_t
1	0.362	0.0423	0.625	14.80	2.40	11.15
2	0.370	0.0433	0.625	14.45	2.48	11.25
3	0.382	0.0447	0.625	13.95	2.60	11.45
4	0.393	0.0460	0.625	13.60	2.74	11.70
5	0.404	0.0472	0.625	13.25	2.74	11.40
6	0.452	0.0529	0.625	11.85	2.60	9.65

TABLE VII OBSERVED DATA GROUP 1 FULL THROTTLE

Run	w_f	h_w	MP	L	BP	t_a
1	0.2200	5.05	28	42.5	28.76	80
2	0.2030	5.05	28	43.5	28.76	80
3	0.1933	5.05	28	44.2	28.76	80
4	0.1867	5.05	28	44.8	28.76	81
5	0.1700	4.90	28	45.2	28.76	81
6	0.1533	4.85	28	44.5	28.76	81
7	0.1400	4.80	28	43.5	28.76	82
8	0.1333	4.75	28	41.3	28.76	82
9	0.1266	4.75	28	40.3	28.76	82
10	0.0112	5.00	28	36.8	28.76	83

OBSERVED DATA GROUP 1 3/4 LOAD

Run	w_f	h_w	MP	L	BP	t_a
1	0.1700	3.75	24.2	36.3	29.12	85
2	0.1560	3.65	24.2	36.6	29.12	85
3	0.1360	3.60	24.2	37.0	29.12	85
4	0.1300	3.55	24.2	36.5	29.12	85
5	0.1160	3.55	24.2	34.9	29.12	85
6	0.1146	3.55	24.2	34.4	29.12	85

TABLE VII OBSERVED DATA GROUP 1 (Continued) 1/2 LOAD

Run	w_f	h_w	MP	L	BP	t_a
1	0.1466	2.2	20	21.6	28.8	80
2	0.1366	2.2	20	23.6	28.8	80
3	0.1300	2.2	20	23.6	28.8	80
4	0.1233	2.2	20	24.6	28.8	80
5	0.1166	2.2	20	24.8	28.8	80
6	0.1116	2.2	20	24.3	28.8	80
7	0.1033	2.2	20	24.0	28.8	80
8	0.0966	2.2	20	23.0	28.8	80
9	0.0933	2.2	20	20.7	28.8	80
10	0.0866	2.2	20	19.6	19.6	80

OBSERVED DATE GROUP 1 1/4 LOAD

Run	w_f	h_w	MP	L	BP	t_a
1	0.093	1.2	15	12.5	29.05	90
2	0.083	1.2	15	13.3	29.05	90
3	0.073	1.2	15	13.3	29.05	90
4	0.066	1.2	15	11.8	29.05	90

TABLE VIII OBSERVED DATA GROUP 2 FULL THROTTLE

Run	w_f	h_w	MP	L	BP	t_a
1	0.2030	3.50	28.50	41.0	29.00	92
2	0.1760	3.30	28.50	43.4	29.00	92
3	0.1530	3.30	28.50	44.3	29.00	92
4	0.1430	3.30	28.50	45.0	29.00	92
5	0.1230	3.10	28.50	45.0	29.00	92
6	0.1060	3.10	28.50	42.5	29.00	92
7	0.1066	2.95	28.50	42.5	29.21	83
8	0.1000	2.90	28.50	40.0	29.21	83
9	0.0960	2.90	28.50	38.5	29.21	83

OBSERVED DATA GROUP 2 3/4 LOAD

Run	w_f	h_w	MP	L	BP	t_a
1	0.0933	2.60	25.0	36.0	29.00	92
2	0.1030	2.50	25.0	38.8	29.00	92
3	0.1160	2.55	25.2	39.5	29.00	92
4	0.1330	2.55	25.2	39.1	29.00	92
5	0.1500	2.60	25.2	38.5	29.00	92

TABLE VIII OBSERVED DATA GROUP 2 (Continued) 1/2 LOAD

Run	w_f	h_w	MP	L	BP	t_a
1	0.1133	1.35	20	23.8	28.9	81
2	0.1100	1.35	20	24.5	28.9	81
3	0.1033	1.40	20	25.1	28.9	81
4	0.0933	1.40	20	25.5	28.9	81
5	0.0866	1.40	20	25.0	28.9	81
6	0.0800	1.40	20	24.0	28.9	81
7	0.0733	1.40	20	21.8	28.9	81

OBSERVED DATA GROUP 2 1/4 LOAD

Run	w_f	h_w	MP	L	BP	t_a
1	0.056	0.75	15	12.5	29	92
2	0.060	0.75	15	13.5	29	92
3	0.066	0.75	15	13.7	29	92
4	0.070	0.75	15	13.4	29	92

TABLE IX OBSERVED DATA GROUP 3 FULL THROTTLE

Run	w_f	h_w	MP	L	BP	t_a
1	0.0700	1.75	28.75	38.8	29	92
2	0.0800	1.75	28.75	42.1	29	92
3	0.0933	1.75	28.75	43.5	29	92
4	0.1060	1.75	28.75	43.5	29	92
5	0.1160	1.75	28.75	43.5	29	92

OBSERVED DATA GROUP 3 3/4 LOAD

Run	w_f	h_w	MP	L	BP	t_a
1	0.0666	1.4	25	34.4	29	92
2	0.0733	1.4	25	37.0	29	92
3	0.0800	1.4	25	37.8	29	92
4	0.0933	1.4	25	38.1	29	92
5	0.1060	1.4	25	38.2	29	92
6	0.1130	1.4	25	38.0	29	92

TABLE IX OBSERVED DATA GROUP 3 (Continued) 1/2 LOAD

Run	w_f	h_w	MP	L	BP	t_a
1	0.0866	0.80	19.5	24.1	29.13	87
2	0.0833	0.80	19.5	24.6	29.13	87
3	0.0800	0.85	20.0	25.2	29.13	87
4	0.0800	0.85	20.0	25.8	29.13	87
5	0.0666	0.85	20.0	26.6	29.13	87
6	0.0633	0.85	20.0	26.5	29.13	87
7	0.0600	0.85	20.0	25.2	29.13	87
8	0.0566	0.85	20.0	26.5	29.13	87

OBSERVED DATA GROUP 3 1/4 LOAD

Run	w_f	h_w	MP	L	BP	t_a
1	0.0333	0.4	14.25	10.0	29.13	87
2	0.0366	0.4	14.00	10.9	29.13	87
3	0.0433	0.4	14.00	11.5	29.13	87
4	0.0500	0.4	14.00	11.1	29.13	87

TABLE X CALCULATED DATA GROUP 1 FULL THROTTLE

Run	W_f	Q	A/F	bhp	e_t
1	13.20	2.230	10.15	14.15	14.00
2	12.20	2.230	11.00	14.50	15.50
3	11.60	2.230	11.55	14.75	16.60
4	11.20	2.230	11.95	14.93	17.40
5	10.20	2.195	12.90	15.05	19.25
6	9.20	2.180	14.20	14.85	21.10
7	8.40	2.170	15.50	14.50	22.50
8	8.00	2.155	16.15	13.75	22.45
9	7.60	2.155	17.05	13.43	23.10
10	7.20	2.210	18.40	12.25	22.20

CALCULATED DATA GROUP 1 3/4 LOAD

Run	W_f	Q	A/F	bhp	e_t
1	10.20	1.92	11.30	12.10	15.50
2	9.36	1.89	12.13	12.20	17.00
3	8.16	1.88	13.18	12.30	19.76
4	7.80	1.86	14.33	12.16	20.30
5	6.96	1.86	16.05	11.63	21.80
6	6.88	1.86	16.50	11.46	21.70

TABLE X CALCULATED DATA GROUP 1 (Continued) 1/2 LOAD

Run	W_f	Q	A/F	bhp	e_t
1	8.8	1.473	10.05	7.2	10.70
2	8.2	1.473	10.80	7.86	12.50
3	7.8	1.473	11.35	7.86	13.15
4	7.4	1.473	11.95	8.20	14.45
5	7.0	1.473	12.65	8.27	15.45
6	6.7	1.473	13.20	8.10	15.75
7	6.2	1.473	14.25	8.00	16.85
8	5.8	1.473	15.25	7.67	17.25
9	5.6	1.473	15.75	6.90	16.15
10	5.2	1.473	17.00	6.54	16.40

CALCULATED DATA GROUP 1 1/4 LOAD

Run	W_f	Q	A/F	bhp	e_t
1	5.6	1.094	11.78	4.17	9.73
2	5.0	1.094	13.20	4.43	11.55
3	4.4	1.094	15.00	4.43	13.15
4	4.0	1.094	16.40	3.94	12.85

TABLE XI CALCULATED DATA GROUP 2 FULL THROTTLE

Run	W_f	Q	A/F	bhp	e_t
1	12.18	1.841	9.080	10.92	11.72
2	10.56	1.790	10.180	11.58	14.30
3	9.18	1.790	11.700	11.80	16.80
4	8.58	1.790	12.520	12.00	18.76
5	7.38	1.735	14.100	12.00	20.60
6	6.36	1.735	16.350	11.27	23.10
7	6.40	1.715	16.100	11.33	23.10
8	6.00	1.700	17.000	10.67	23.20
9	5.80	1.700	17.550	10.26	23.10

CALCULATED DATA GROUP 2 3/4 LOAD

Run	W_f	Q	A/F	bhp	e_t
1	5.60	1.59	17.10	9.60	22.40
2	6.18	1.56	15.13	10.35	21.85
3	6.96	1.57	13.54	10.53	19.75
4	7.98	1.57	11.80	10.42	17.07
5	9.00	1.59	10.60	10.27	14.88

TABLE XI CALCULATED DATA GROUP 2 (Continued) 1/2 LOAD

Run	W_f	Q	A/F	bhp	e_t
1	6.8	1.155	10.20	6.35	12.20
2	6.6	1.155	10.50	6.54	12.90
3	6.2	1.175	11.35	6.70	14.10
4	5.6	1.175	12.60	6.80	15.85
5	5.2	1.175	13.55	6.67	16.75
6	4.8	1.175	14.20	6.40	17.40
7	4.4	1.175	15.50	5.81	17.50

CALCULATED DATA GROUP 2 1/4 LOAD

Run	W_f	Q	A/F	bhp	e_t
1	3.4	0.852	15.20	3.33	12.80
2	3.6	0.852	14.20	3.60	13.05
3	4.0	0.852	12.90	3.65	11.90
4	4.2	0.852	12.17	3.57	11.10

TABLE XII CALCULATED DATA GROUP 3 FULL THROTTLE

Run	W_f	Q	A/F	bhp	e_t
1	4.2	1.302	18.60	7.76	24.00
2	4.8	1.302	16.30	8.43	22.90
3	5.6	1.302	13.95	8.70	20.30
4	6.4	1.302	12.30	8.70	17.75
5	7.0	1.302	11.22	8.65	16.13

CALCULATED DATA GROUP 3 3/4 LOAD

Run	W_f	Q	A/F	bhp	e_t
1	4.0	1.168	17.50	6.88	22.40
2	4.4	1.168	15.95	7.40	21.90
3	4.8	1.168	14.60	7.56	20.60
4	5.6	1.168	12.50	7.64	17.80
5	6.4	1.168	11.00	7.64	15.57
6	6.8	1.168	10.32	7.60	14.60

TABLE XII CALCULATED DATA GROUP 3 (Continued) 1/2 LOAD

Run	W_f	Q	A/F	bhp	e_t
1	5.2	0.849	9.79	4.82	12.10
2	5.0	0.849	10.20	4.92	12.85
3	4.8	0.875	10.95	5.04	13.70
4	4.8	0.875	10.95	5.16	14.04
5	4.0	0.875	13.10	5.32	17.40
6	3.8	0.864	13.62	5.30	18.20
7	3.4	0.864	15.23	5.05	19.35
8	3.4	0.875	15.45	5.30	20.30

CALCULATED DATA GROUP 3 1/4 LOAD

Run	W_f	Q	A/F	bhp	e_t
1	2.0	0.6	18.00	2.00	13.05
2	2.2	0.6	16.40	2.18	12.95
3	2.6	0.6	13.85	2.30	11.55
4	3.0	0.6	12.00	2.25	9.79

TABLE XIII OPTIMUM VALUES FOR PROPANE

Rpm	Load	A/F	bhp	e_t	S_p
2000	Full	12.10	14.25	16.80	0.721
2000	3/4	11.90	11.57	15.70	0.763
2000	1/2	12.70	7.85	14.55	0.803
2000	1/4	12.35	4.13	10.00	1.173
1600	Full	13.6	10.350	17.3	0.680
1600	3/4	12.5	9.970	16.4	0.721
1600	1/2	14.7	6.405	16.6	0.778
1600	1/4	14.7	3.790	12.8	0.908
1200	Full	13.70	7.84	17.00	0.676
1200	3/4	13.85	6.94	17.20	0.672
1200	1/2	13.10	5.20	15.30	0.769
1200	1/4	13.45	2.75	11.55	1.015

TABLE XIV OPTIMUM VALUES FOR GASOLINE

Rpm	Load	A/F	bhp	e_t	S_p
2000	Full	13.10	15.05	19.5	0.664
2000	3/4	13.75	12.30	19.5	0.667
2000	1/2	12.75	8.27	15.1	0.838
2000	1/4	12.50	4.48	12.5	1.275
1600	Full	13.30	12.40	19.80	0.631
1600	3/4	13.00	10.54	19.00	0.686
1600	1/2	12.60	6.80	15.85	0.823
1600	1/4	13.35	3.66	12.50	1.045
1200	Full	13.15	8.70	19.10	0.684
1200	3/4	11.75	7.66	16.75	0.777
1200	1/2	13.45	5.33	18.30	0.723
1200	1/4	14.25	2.30	11.75	1.100

TABLE XV VOLUMETRIC EFFICIENCY AT FULL THROTTLE

PROPANE:

Rpm	Efficiency
2000	68.3%
1600	66.7%
1200	67.6%

GASOLINE:

Rpm	Efficiency
2000	75.3%
1600	75.0%
1200	72.8%

TABLE XVI MAXIMUM EFFICIENCY VALUES

PROPANE:

Rpm	Throttle Setting	Efficiency
2000	Full	20%
1600	Full	19.75%
1200	Full	18.55%
2000	3/4	17.00%
1600	3/4	16.85%
1200	3/4	18.65%
2000	1/2	15.50%
1600	1/2	17.85%
1200	1/2	16.20%
2000	1/4	10.45%
1600	1/4	12.80%
1200	1/4	11.70%

GASOLINE:

Rpm	Throttle Setting	Efficiency
2000	Full	23.10%
1600	Full	23.20%
1200	Full	24.00%
2000	3/4	21.80%
1600	3/4	22.40%
1200	3/4	22.40%
2000	1/2	17.30%
1600	1/2	17.70%
1200	1/2	19.35%
2000	1/4	13.32%
1600	1/4	13.05%
1200	1/4	13.20%

APPENDIX III

SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

A. Brake Horsepower

$$bhp = \frac{2IIL(DC)N}{33,000}$$

The dynamometer is given by the manufacturer so that

$$bhp = \frac{L(DC)}{6000}$$

B. Pounds of gasoline per hour

$$W_f = w_f \text{ X } 60$$

C. Pounds of propane burned per hour

$$w_f = \frac{W_p}{v_{sp}}$$

D. Pounds of fuel per brake horsepower hour

For propane $S_p = \frac{w_p \text{ x } 60}{bhp}$

For gasoline $S_p = \frac{w_f \text{ x } 60}{bhp}$

E. Density of the air

$$d_a = \frac{1.325(BP)}{T}$$

F. Pounds of air flowing into the engine per minute

$$Q = 0.756CD^2 \quad \frac{h_w \, d_w}{d_a}$$

The orifice coefficient C was obtained in the following manner. The diameter of the pipe leading into the surge chamber was 2 inches. The diameter of the orifice was one inch. The ratio of the orifice diameter to the pipe diameter was 0.5. Applying this value to the chart[1] of constants for thin plate orifices the

[1]Severns, W. H. and Degler, H. E., Steam, Air and Gas Power, John Wiley and Son, Inc., New York, 1948, p. 399

corresponding orifice coefficient was determined. From this chart was also found the exit side factor which was used to determine the distance of the vena contracta taps from the orifice.

G. Determination of flow of propane at standard conditions:

$$\frac{P_s V_s}{T_s} = \frac{P_p V_p}{T_p}$$

H. Thermal efficiency:

$$e_t = \frac{2545 bhp}{H_p W_p}$$

$$e_t = \frac{2545 bhp}{H_f\ W_f}$$

I. Cubic feet of propane per minute:

$$V_p = \frac{2 \text{ cu ft } (60)}{t}$$

J. Pounds of propane burned per minute:

$$w_p = \frac{V_s}{v_{sp}}$$

K. Air to fuel ratio:

Propane:

$$A/F = \frac{Q}{w_p}$$

Gasoline:

$$A/F = \frac{Q}{w_f}$$

L. Volumetric Efficiency:

$$m_t = \frac{68.7\ (\text{Cycles/min.})(d_a)}{1728}$$

$$e_v = \frac{m_a}{m_t}$$